Control ENGINEERING

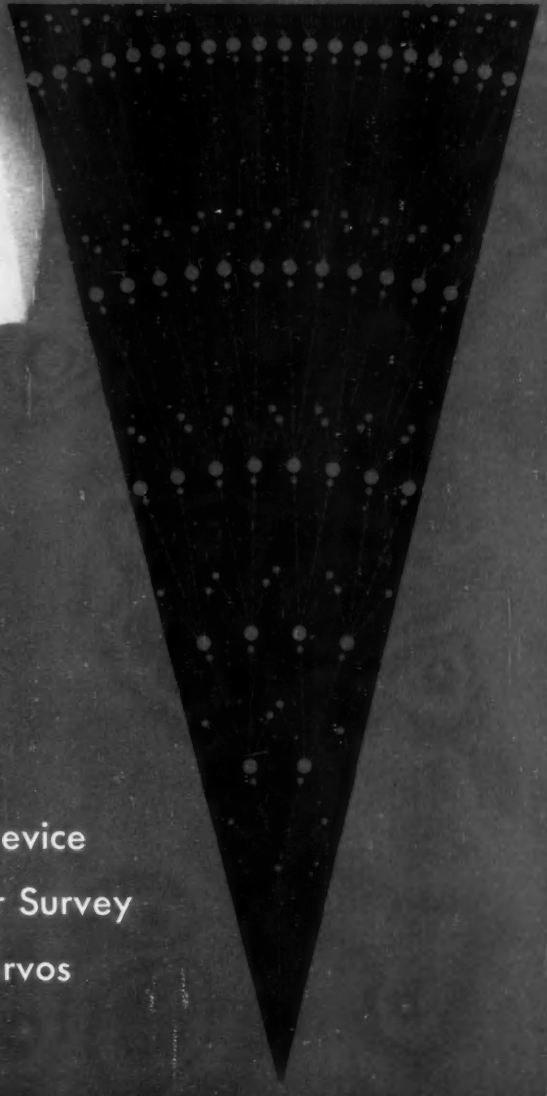
A McGRAW-HILL PUBLICATION

PRICE 50 CENTS

AUGUST 1955

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

NUCLEAR ENERGY CHALLENGES CONTROL



ALSO IN THIS ISSUE

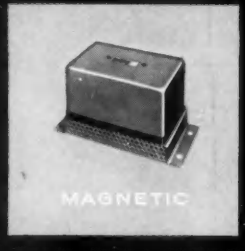
A New Memory Device

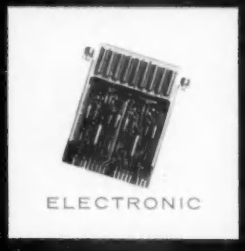
Timer-Programmer Survey

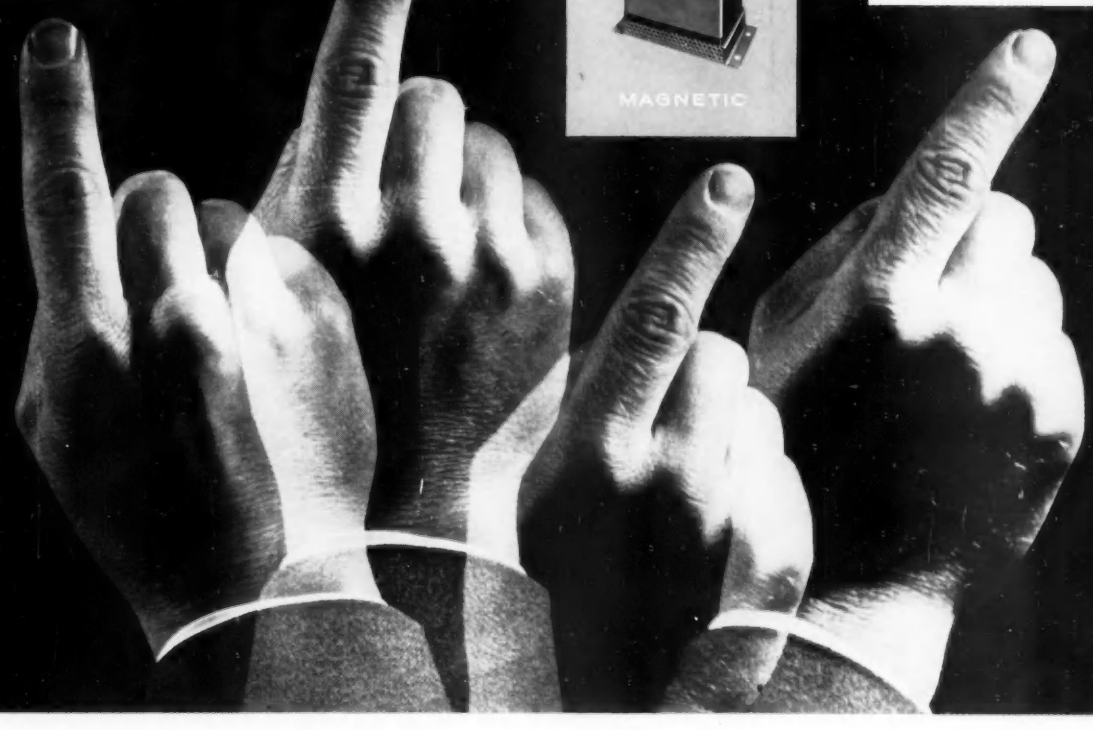
Tach-Stabilized Servos

TURNING WITH EASE...

from one thing to another







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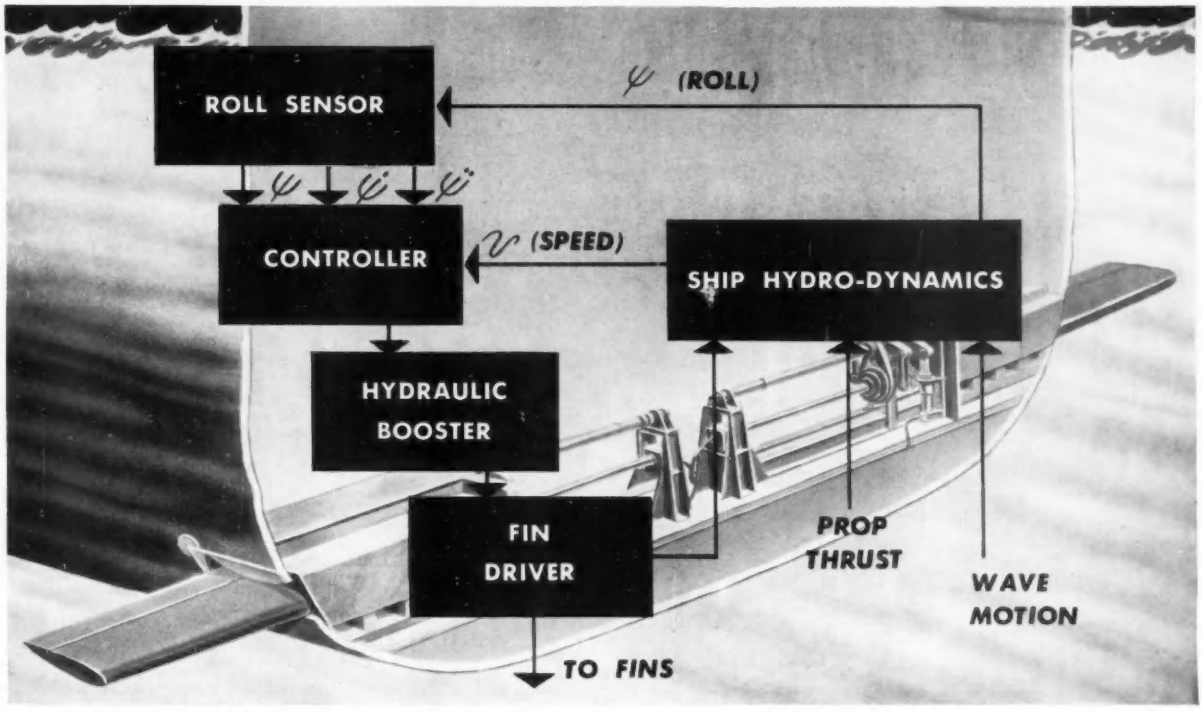
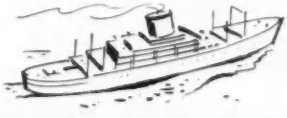
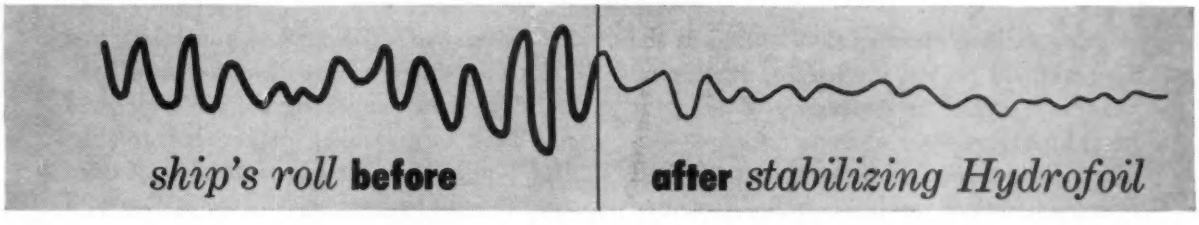




example: **How to make a ship behave**



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- Telemetering
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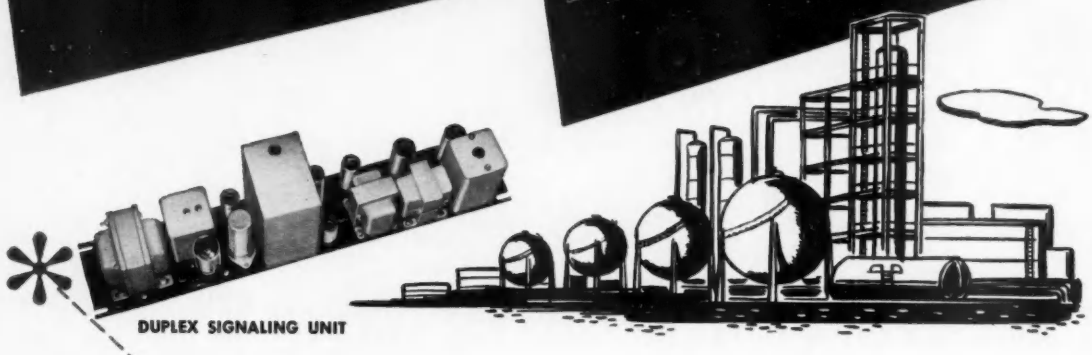

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Control ENGINEERING

AUGUST 1955

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

FEATURE ARTICLES

A New Approach to Information Storage — Gilbert W. King 48

Control of Nuclear Reactors — J. A. Dever 54

Another Use for the Sphere: The Tangent Integrator — Edward Burgess 63

Four Questions About Control Timers — J. Graham 65

Graphical Integration by Pole-and-Ray — A. S. Levens 71

These Seven Steps Design a Tach Stabilized Servo — Jules E. Kadish 72

IDEAS AT WORK

Get Most from Centrifuges — W. K. Klager 80

Radio Loop Curbs Wayward Cranes 81

Actuator Has Low Standby Power — A. Goodwin, D. Morrison 82

Sensors for Gaseous Diffusion 85

Simple Accelerometer Calibration — V. B. Corey 87

TV Sharpens Measurements 89

DEPARTMENTS

Control Personality – Don Eckman 11

Industry's Pulse—Nuclear Energy Breeds New Markets for Control 41

Editorial – Your Place in Nuclear Control 47

Shoptalk 4 — Bulletins and Catalogs 105

Feedback 6 — Abstracts 110

What's New 12 — Books 113

New Products 90 — Meetings Ahead 116

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ADVERTISING INDEX 122

PRINT ORDER THIS ISSUE 27,341

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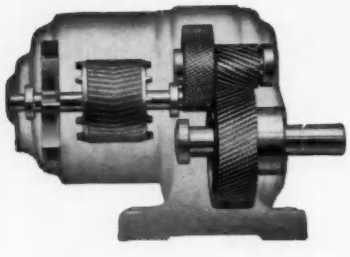

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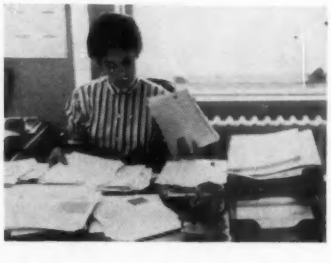
CONTROL WITH A NUCLEAR TINT

This issue honors the Geneva Conference on Peaceful Uses of Atomic Energy (see *What's New*, page 13). Take the cover. We got the idea when Lloyd Slater's in-law, Dr. Frank Kertesz, dropped in to visit. Frank was on his way from Oak Ridge to watch construction of ORNL's "swimming pool" reactor exhibit in Geneva. Linguist-scientist Kertesz will be Chief Guide and is all primed to answer questions in French, German, Italian, Spanish, and even English, about the "swimming pool's" fascinating underwater glow. What, thought we, would be a more appropriate nod to Geneva than a cover with this nuclear glow? We challenged Jack Gordon to catch it in only one color. What do you think of the result?

SUSAN IS HAPPILY SNOWED

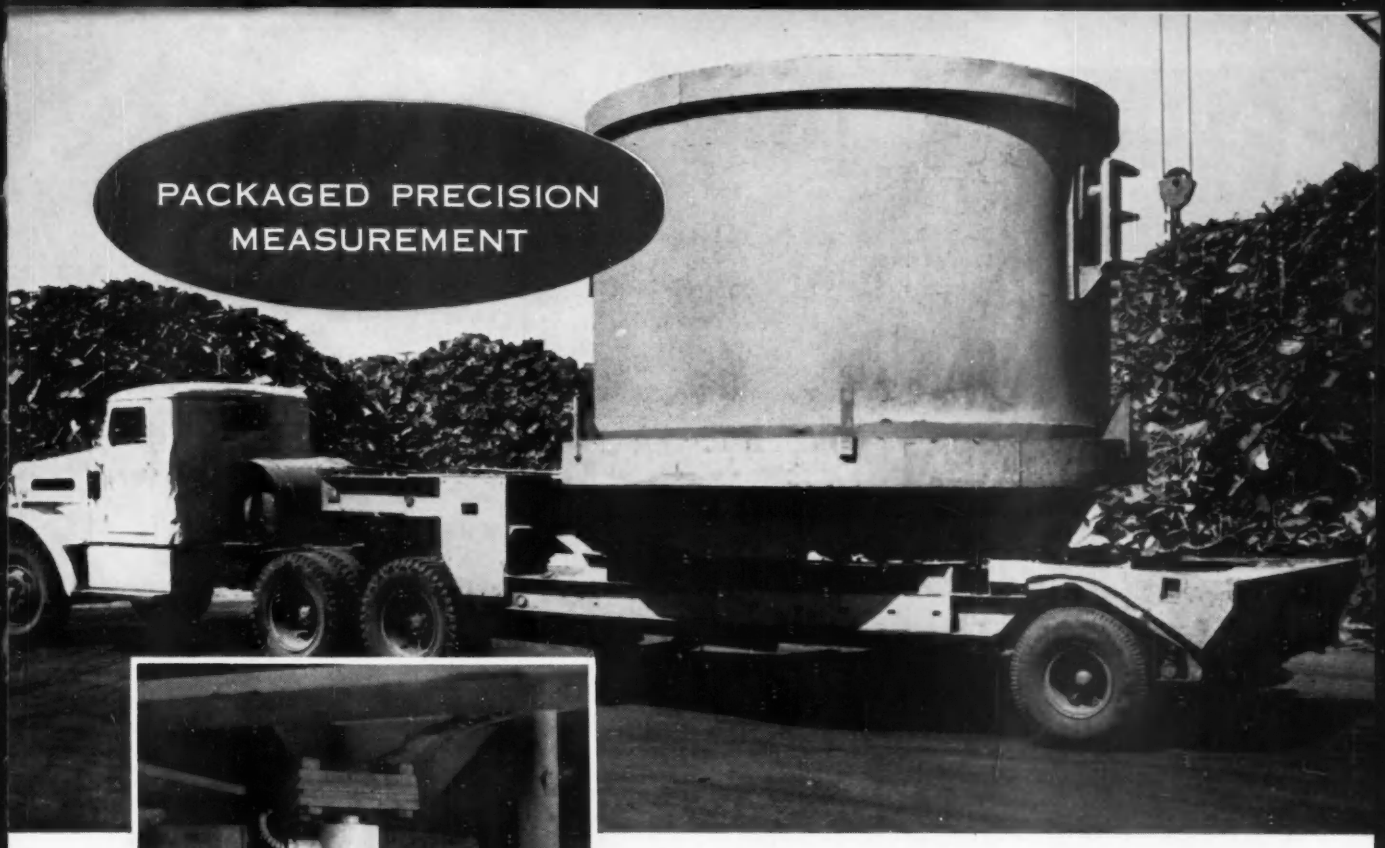
Readers, we are happily snowed by your requests for reprints of past articles. Actually, while we're all happy, it's Sue Richmond who's snowed. Sue is the gal who bravely rustles through a few hundred letters each month and bounces reprints back at you. Though buried in paper, she keeps asking for more. For instance, "Who would like complete back issues now out of print? We could offset them in book form." Send us enough "yeahs" and we'll do it.

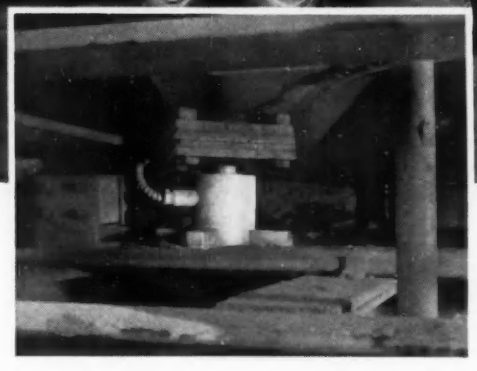


Susan probes, peers, ponders, and then produces the article you asked for.

AUGERNIZING A SHOW

Back last spring, while talking about our part in the forthcoming Production Engineering Show in Chicago, Sept. 6-16, Will Garey got another of his gifted ideas. "What a trade show needs," said Will, "is Editorial Content. Why not invite the Universities to display some of their lab-bench concepts of control—sort of a Tomorrow's Techniques Section?" Ray Auger was delegated to tour the institutions and zero-in on possible exhibits. Our only contact with Ray in May was sporadic 'phone conversations from spas like Ithaca, Ann Arbor, and Urbana. But when he came home to roost, quite a show was organized. Read the details on page 24.





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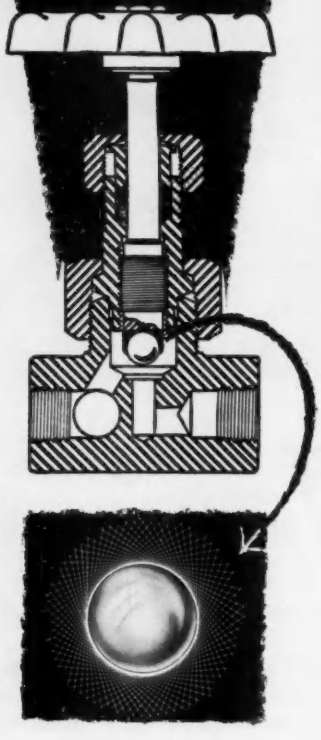

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FEEDBACK

Needed: Technicians—Everywhere

To the Editor—

Your June editorial, may I suggest, could well be followed by one entitled, "Needed: Technicans at Home". As you are certainly aware, the Engineering Manpower Commission of the Engineers Joint Council is busily crying the story of America's desperate need for engineers, and the fact that Russia's engineering schools are outproducing ours by about three to one.

At the same time, the Institute of Radio Engineers says that we need five technicians for every engineer so that we can release the ones that we already have from technician's duties so that they may handle the engineering work for which they have been trained.

Industry could do itself a great favor by taking its own personnel (of which there are considerably more than there are high school students about to graduate), and sending them to accredited technical institutes.

What with the coming automatization, the need is going to increase one-thousandfold. You of Control Engineering have already astutely surmised this by the very fact of your starting this publication. We'd better get started here at home before we do in Europe or Africa or we'll be running right up our own backs.

Stanley C. Marshall
Pittsburgh, Pa.

On the Control Engineering Map

To the Editor—

Many thanks for sending me a copy of your May issue with the personality item which you were good enough to prepare. I appreciate very much this kind thought of yours as well as of other friends who initiated this coming back to a distant past.

Mr. Al Sperry and his wife have just left us a couple of days ago. We were very happy to welcome them here. We hope that you shall be able to visit the Old World and that your path will go through this place in the very heart of the old "Provincia Romana".

N. Minorsky
Aix-en-Provence
France

• • •

PROBLEM FORUM

A bevy of articulate readers responded to the Problem (right) we ran in June. Two cash-winning solutions start on the opposite page. Why don't you send in your problem? If it's a good one, you'll not only get cash, too, but some interesting slants from the 250,000 years of experience of our readers.

Back to June's Problem

To the Editor—

A flowmeter (rotameter principle) measures a flow rate. The measurement is converted to a 0 to 30 mv (100 ohms) signal. The problem is to determine the *entire* volume during an interval of time (for instance, during 24 hours) and to transmit to the integral to a recorder. What circuits and meter types would be suitable? Keep in mind simplicity and reliability.

Heinrichs Apparatebau
Koeln-Lindenthal, Germany

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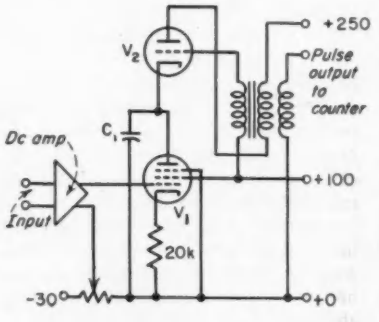
Two Answers To June's Problem

Tailor made solutions.

TO THE EDITOR—

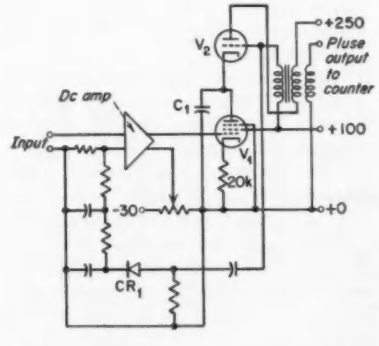
Here are my suggested solutions to the problem posed:

TYPE 1: The input (0-30 mv) is fed to a linear, drift-free dc amplifier, perhaps of the chopper type, with a gain of about 700. The amplifier out-



put is fed to V_1, which is biased to cutoff for 0 input. The cathode resistor assures that the plate current of V_1 will be a linear function of the input voltage and independent of other factors. V_2 is a blocking oscillator with a timing condenser in its cathode circuit. The frequency will be proportional to the rate of discharge of C_1, which is controlled by V_1. Therefore, the output frequency will be proportional to the input voltage. By proper choice of values, the circuit can be made to emit one pulse for each 100 millivolt-sec, for example. The pulses can then be fed either to an electronic counter, or if slow enough, to a vacuum tube relay and a printing register.

TYPE 2: This is esesntially the same as Type 1, except that the dc



amplifier should have a much higher gain, and there is no requirement for

digital data recording systems

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POSITION

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FORCE

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VOLTAGE

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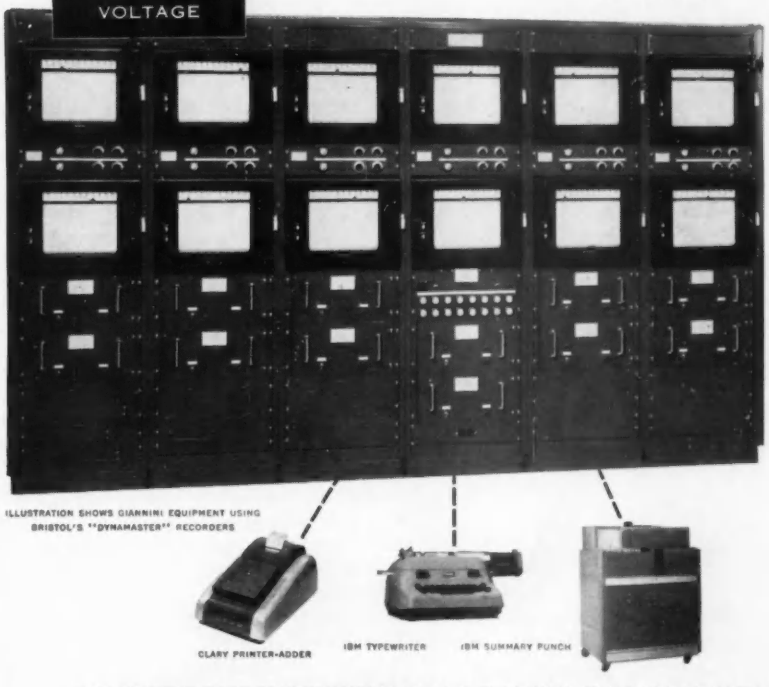

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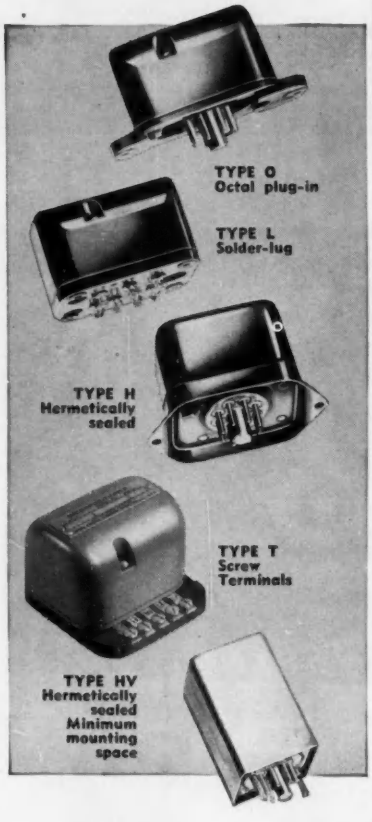

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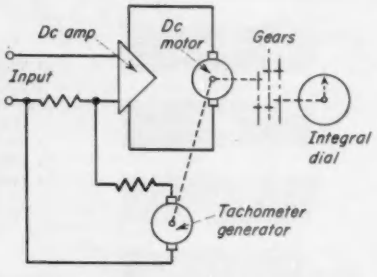
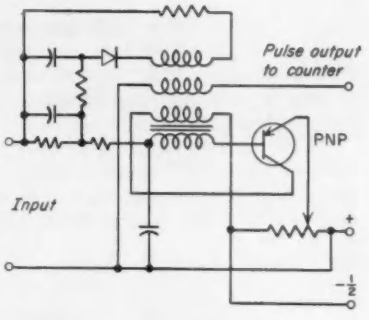
linearity. Because the output voltage of a blocking oscillator is independent of frequency, the voltage fed back by CR_1 will be proportional to the frequency; therefore, by feedback theory, the frequency will be proportional to the input voltage.

TYPE 3: Here a power dc amplifier is used to drive a dc motor which



feeds back by means of a tachometer generator. Velocity is therefore proportional to input voltage, and the integral can be read on dials or printed by a mechanically-driven set of printing wheels. This system would be more expensive because of the motor-generator and gears.

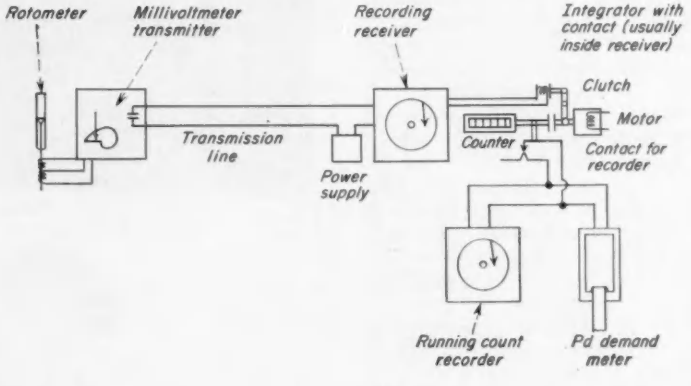


TYPE 4: This follows the system of Type 2. No dc amplifier should be required, but accuracy would be sacrificed for the gain in reliability and saving on cost.

Of these four systems, Types 1 and 2 seem to offer the most promise. Electronic pulse counters are commercially available, especially in the nuclear field. Some have printing registers.

Richard K. Dickey
Berkeley, Calif.

2. A Ready-Made Solution



TO THE EDITOR—

In this system measurement is converted into an impulse whose duration is proportional to reading and this impulse is transmitted over any convenient communication facility. In the receiver, the impulse is reconverted to motion which reproduces the reading with a pointer or pen. For integration, this impulse actuates a clutch between a synchronous motor and a counter so that the counter reading is calibrated in total flow.

The integrator can be equipped with a contact to record the total with respect to time. This contact makes momentarily for a given flow increment, a "Running Count Recorder" recording the total of the contact closings.

To obtain the total at the end of pre-selected intervals, attach a General Electric P. D. Demand Meter to the integrator contacts. This instrument will print, on a strip of paper tape, the total since the last print.

The sketch shows the integrator outside the flow recorder case, although it is usually placed inside the case. Incidentally, the integrator may be located at the transmitter.

L. B. Lumpkin
Birmingham, Ala.

Rigorous and Vigorous Feedback

Harold Levenstein's article, "Pneumatic Servomechanisms", [CONTROL ENGINEERING, Vol. 2, No. 6] is timely and interesting. There are without doubt many control problems that can be effectively solved with the help of high performance pneumatic control elements. Reading this article prompts me to offer a few comments which are intended to try to point up a number of vital factors that have been neglected in the author's treatment, without discouraging the potential user of this excellent mode of power control.

First, the treatment of valve characteristics is greatly over-simplified. Even the most precisely made pneumatic servovalves are, to some extent, open-center valves and fairly sensitive to load pressure changes. That is, the flow is a function of load pressure as well as valve stroke. This means that a valve-controlled ram is not a perfect steady state integrator in the presence of varying external loads.

It is also true that valves have been made intentionally open-center in varying degrees for many years in order to attain the additional damping that accrues from the "leaky" effect present in an open-center valve. When this is done, the transfer function for the valve-controlled ram system is somewhat more complicated, even though it is still a third order differential equation. From one point of view, the resistance and tank scheme [Figure 5 of cited article] with a closed-center valve is simply a transient leakage effect that makes it possible to get vital system damping without sustaining large variations in performance due to steady loads that would accrue from using an open-center valve. Incidentally, some care must be exercised to get a truly capillary pneumatic resistance because of the very low viscosity of air, and even then it has been shown that the flow of compressed air through a capillary varies as the difference of the squares of the upstream and downstream pressures. Analog and experimental studies at M.I.T. have shown that each of the "stabilization chambers" should usually have at least three times the volume in one end of the ram cylinder when the ram is centered.

Reference: "Study of Pneumatic Processes in the Continuous Control of Motion with Compressed Air" by J. L. Shearer, ASME Paper No. 55-IRD-4.

Cambridge, Mass.
J. L. Shearer

Any rebuttal?—Ed.

BARBER COLMAN

Small Motors

selected to power RICHOMATIC remote control television tuner

With a "Rich O Matic" television remote control, the TV viewer can sit in his chair any place in the room and have complete control of his set. Handy palm fitting control turns set on and off, changes stations, adjusts volume, picture, and tuning.

Heart of the "Rich O Matic" is a coil tuner, operated by a Barber-Colman EYAZ geared reversible small motor, and interconnecting electronic circuits. This assembly is mounted in a completely shielded sub-chassis which is positioned out of sight inside the television cabinet.

"Plus" features of the highly dependable Barber-Colman motor used in this application include high torque to inertia ratio . . . low-voltage (24 volt) 3-wire control of reversing circuit . . . rugged, precision-built gear train . . . porous bronze bearings . . . hardened and ground stainless steel rotor shafts.

If you have a project involving small motors, let Barber-Colman engineers work with you to get the exact motor for the job.

Free Data Service on Wide Line of Small Motors

The Barber-Colman line includes unidirectional, synchronous, and reversible motors—up to 1/30 hp. With and without reduction gearing—open or enclosed types. Expert engineering service available. Write today, tell us your problem, ask for free data sheets.

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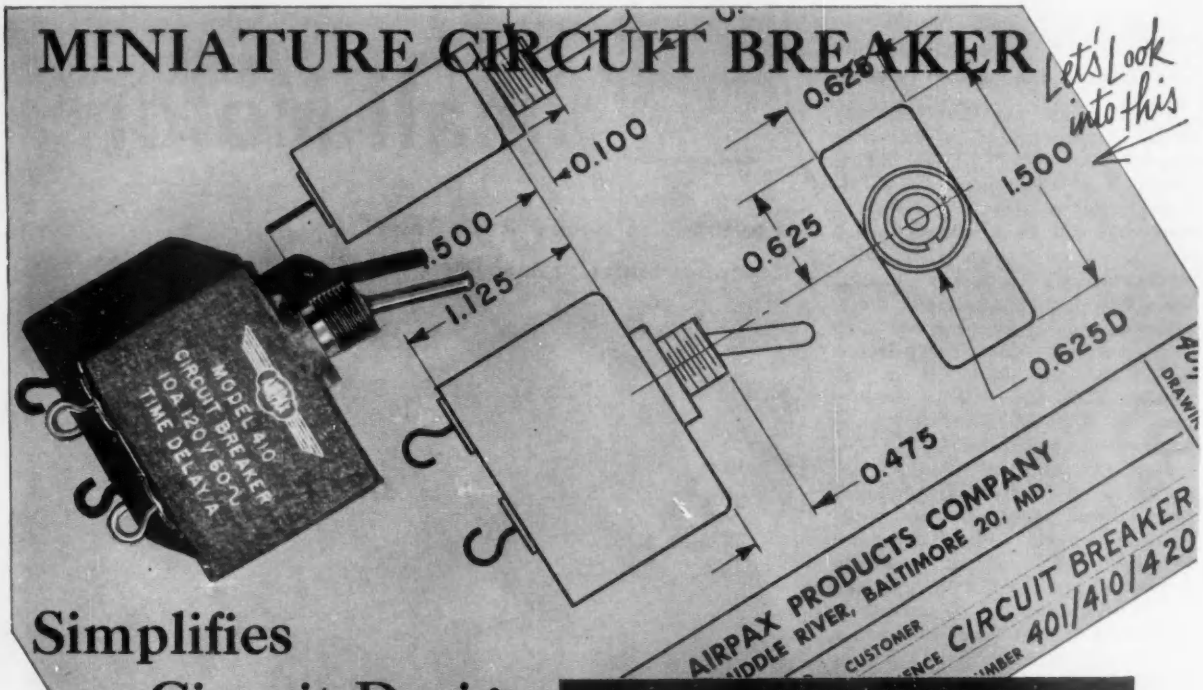
Small Motors • Automatic Controls • Industrial Instruments • Aircraft Controls • Air Distribution Products • Overdoors and Operators • Molded Products • Metal Cutting Tools • Machine Tools • Textile Machinery

MINIATURE CIRCUIT BREAKER



Simplifies Circuit Design

You can now perform the *two* functions of power ON-OFF control and circuit protection with *one* miniature fully magnetic time-delay trip-free circuit breaker. Save space (see diagram above); save weight (weighs less than 2 oz). The characteristics (tabulated at right) of this new Airpax component show it to be a significant advance in power control; just what you need.

Handle has ON and OFF positions; it moves to OFF position when breaker trips, yet breaker cannot be prevented from tripping by holding handle in ON position. Stable tripping mechanism assures reliable operation even under adverse temperature and vibration. Give your equipment the protection it deserves.

To restore service after fault has been removed, simply reset the breaker. A breaker having a 30-sec time delay recovers full delay in about 20 sec.

To receive complete engineering data, simply write to

CHARACTERISTICS

RATINGS: 0.05 amp to 10 amp at 50 V DC or 1.0 to 10 amp at 120 V AC

MINIMUM TRIP: 125% of rated load

INSTANTANEOUS TRIP: 1,000% of rated load

INTERRUPTING CAPACITY: a typical value is 500 amp at 30 V DC

POWER CONSUMPTION: 0.6 watt in lower current ratings, rising to about 2 watts at 10 amp rating

SHOCK: resists 50 g in all directions

VIBRATION: 10 to 55 CPS at 0.06 in. total excursion in all directions

TEMPERATURE: −40 C to +100 C

LIFE: 10,000 operations at rated current into resistive load

ENCLOSURE: hermetically sealed

AIRPAX

ENGINEERS DESIGNERS

MIDDLE RIVER BALTIMORE 20, MD.

A
CONTROL
PERSONALITY

DON ECKMAN
primes a growing field

In 1945 John Wiley & Sons published a book concerning a field about which, until that time, little had been written. The book: *Principles of Industrial Process Control*. Its author: Donald P. Eckman, a young development engineer in the Brown Instruments Div. of Minneapolis-Honeywell. Today Eckman, whose book proved to be a sort of vanguard for a flock of texts on automatic control, is not only Professor of Instrumentation Engineering (newly minted) in the Mechanical Engineering Dept. of Case Institute of Technology, but is the kind of author-educator who stimulates his fellows by his fever-pitch activity in a host of other fields.

Don, who's also a musician, sportsman, and gifted raconteur, brought out his second book on automatic control, *Industrial Instrumentation*, during the period that began in 1946 when he went to Cornell to study and teach, and to start his present association with Conoflow Corp. as a consultant. He authored the "Instrumentation" section of *Kent's Mechanical Engineers' Handbook* soon after this, and in 1950 received his PhD. That fall he joined Case Institute, where he teaches automatic control to undergraduates and to industry.

Dr. Eckman runs a frequency response test on a Conoflow pneumatic valve actuator. Developed in the course of his consulting, the equipment is now used by students in the automatic control laboratory at Case.

No Margarine Shortage at Case

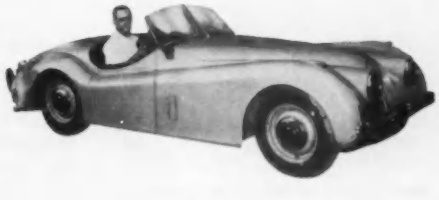
In an heroic effort to clarify the problems and perfect the techniques of industrial control, Don and associate Irving Lefkowitz have set up in Case's Chemical Engineering Laboratory a computer-controlled hydrogenation process. The product: oleomargarine. Alone, he is avidly pursuing another objective: a super high dynamic performance hydraulic actuator for contour lathes. And when he's not in the lab, or writing his third book on automatic control, the amazing Eckman is consulting for Leeds & Northrup on electronic control.

Technical societies eagerly seize him (if they can) as a speaker at their meetings. In fact, he's delivered the principal talk at some thirty sessions. During the past academic year he conducted an industrial class that met once or twice a week at the Philadelphia plant of Leeds & Northrup. The professor commuted from Cleveland by round-trip plane.

Don's musical bent harks back to stints as a saxophonist in college bands. This verve, still very much there, is marked today by an antique reed organ, a Hammond electric organ, a baby grand that Don completely rebuilt, and the youthful galaxy who attend his wife, Jeanette's, very successful music school (five little Eckmans also are pupils). Characteristically, the family vacuum cleaner, pumping from the basement, powers the reed organ.

Jag Replaces Bike

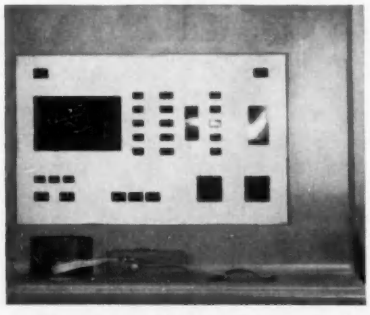
After Don received his PhD, he and Jeanette flew to Europe and cycled through the Scandinavian countries. The bikes gave way to a Singer sports car, which, in turn, bowed to a Jaguar. With customary zeal, the engine will be completely torn down and all parts Magnafluxed and reassembled. Thus the Jag will be optimized for speed trials this summer. Watch your rearview mirror.



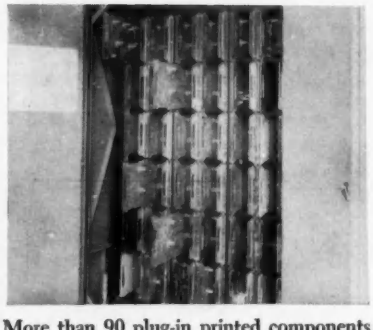
1. It starts with numerical data pre-calculated from engineering drawings of the complicated work piece. These, along with tooling studies and machine tool feed rates, are fed into the paper tape preparing unit operated by the girl at the desk. A 16-key keyboard transcribes data into decimal-digital form. At the same time a visual checking copy is automatically typed and punched-hole accuracy is verified by logical circuits.

2. Punched tape is then passed into the computing director (seen above against the wall) which converts data into time-space electrical signals and channels these onto master magnetic tape.

Automatic Control Now Harnesses Complex Machining



Paper-tape reader feeds digital data to the programming computer. Five coarse repeaters show machine axes position.



More than 90 plug-in printed components are used in the "Numericord" system.

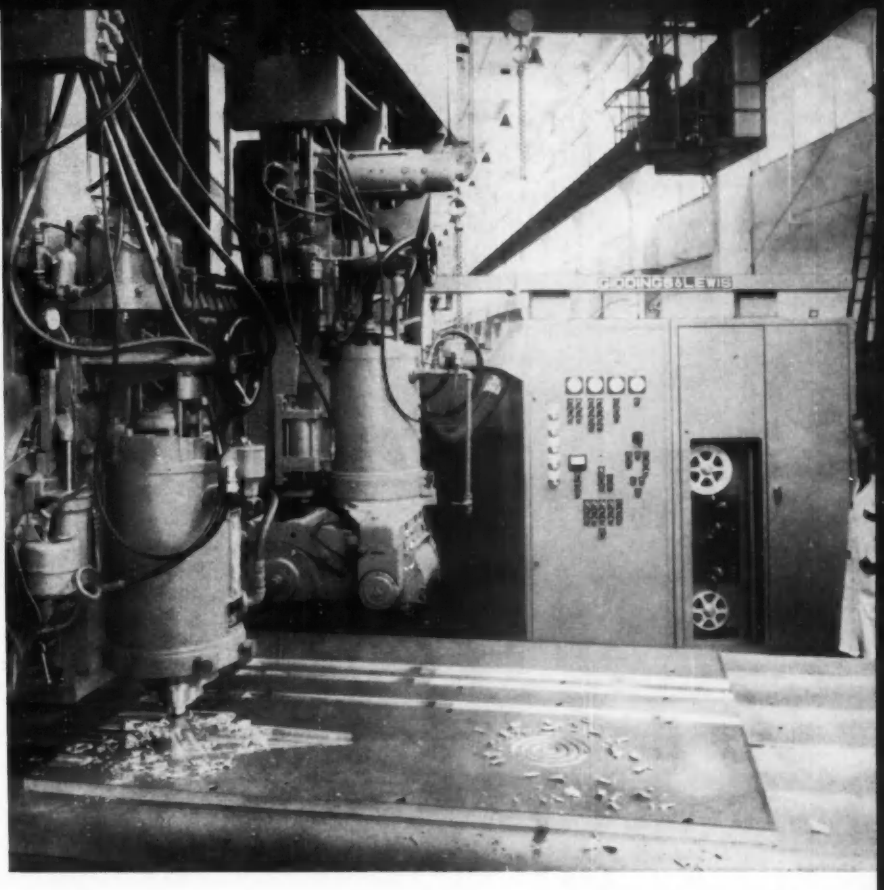
Rare indeed was the control engineer passing near Boston during the past two years who did not try to snatch a furtive peek at an advanced use of his art in the machining field. And even the TV public got a quick look when in November CBS spotted the prototype machine control into "The Search" (see CONTROL ENGINEERING, January, 1955, p. 12). But now the tease is over—the wraps are really off for good on the Giddings and Lewis machine control project.

The official unveiling of G&L's "Numericord" system took place June 8 in the company's own bustling Fond Du Lac plant. Besides members of the long-alerted press, cramming the demonstration area were aircraft and Air Force people, as well as some of the General Electric and Massachusetts Institute of Technology engineers who helped develop the system.

Those who saw the well-staged demonstration were amply rewarded for the long trek to upper Wisconsin. Out on the spruced-up factory floor was a giant double-headed spar and skin-miller—the king-sized machine that fashions intricate wing shapes for jets. On its 7 by 14 ft table lay a door-sized aluminum workpiece. Not a machinist was in sight as the two heads moved sleekly—one up and down, the other profiling—to mill out the darndest patterns (including the pert Archimedean spiral seen in the large picture above). Also robot-milled: a horizontal stabilizer for the new F-100D Sabre Jet fighter.

While the pictures and captions briefly describe the system and its components, they barely suggest its remarkable flexibility. For example, verbal commands can be added to the tape to alert the panel attendant just before tools should be changed or a cycle nears its end. These peal out from a panel loud-speaker. And then there is the neatly designed servo system that operates in a closed loop with the tape reading heads. Machining motions—produced by servo motors responding to amplidynes—are picked up by synchros that feed back to phase discriminating circuits. The discriminators compare output and input signals and continuously balance out the difference. The system is able to control simultaneously five machine axes in three dimensions, and will perform 22 auxiliary functions.

At Fond Du Lac, a bright, office-like room just off the production floor



3. Master tape is pulled from office recorder (above) and placed in playback panel to control machining process.

housed the tape making demonstration. Here an operator at a keyboard tapped away to translate data into digit perforations on a paper tape. The uncluttered desk was deceptively idle. Tucked inside were racks of tubes and relays—a logical control circuit to check the accuracy of the operator's translation. Some of the automatic checks: spotting the omission of plus or minus signs in distance commands and pinpointing deviations from established feeds or distance values. The supervisory circuit also added holes to the tape for logical control of the system's computing director. Besides its ambidextrous desk, the tape-making room held a soberly cabineted computer to coordinate data in terms of time and motion and a director to program the information onto magnetic tape.

Already a highly developed "package", the Gidding and Lewis system is not limited to controlling skin millers. It is also designed to work on horizontal boring mills, vertical boring mills, and drilling machines. It offers inherent accuracy within 0.0005 in. in its magnetic tape, and resulting mechanical accuracy of within 0.002 in. All parts of the system are commercially standard. And almost all of its electronic parts are of block-component design and use printed circuitry.

ATOMIC ITEMS

Geneva Conclave Promises Strides in Nuclear Control

Nuclear control—on the engineering level, that is—should zoom ahead after this summer's International Conference on Peaceful Uses of Atomic Energy (Geneva, Switzerland, Aug. 8-20). And there is an excellent chance that control on the socio-political level will benefit, too.

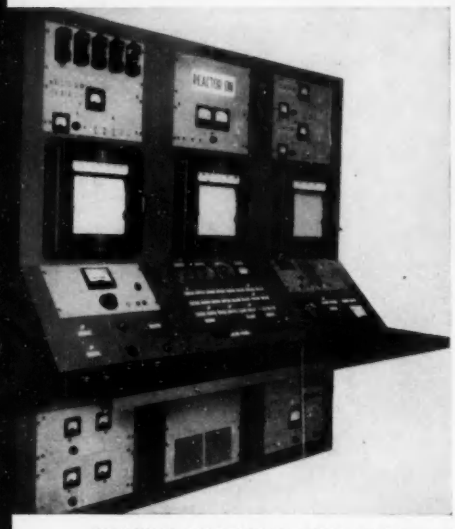
The reason for optimism is Geneva's all-out technical program—sort of spontaneous international relaxation of information that had been hush-hushed into obscurity during years of the cold war.

France, Russia, England, and the United States will contribute the bulk of the near-to 1,000 papers. At least 50 of these will deal with problems of measuring and controlling nuclear energy. Some samples: France—Complete Control of a Nuclear Reactor; U.S.S.R.—Use of Radioisotopes in Technological Process Control Instruments; Great Britain—Neutron Flux Instrumentation Systems for Reactor Safety and Control; U.S.—Time of Flight Instrumentation for Neutron Spectrometer.

CONTROL ENGINEERING did its bit for atomic amity when former Managing Editor George Boehm went to McGraw-Hill's Technical Writing Service. George became Editor of the nine-volume opus on U.S. nuclear know-how which will be handed to each U.N. delegate to the Conference.

Land of Sky Blue Reactors

Local nuclear energy may soon be considerably less "sky blue" than the 10,000 famed lakes, now that three



REACTOR PACKAGE: This L&N panel now controls Penn State's new swimming pool reactor. It regulates neutron flux density and includes all safety interlocks.

of Minnesota's most energetic firms —Minneapolis-Honeywell, General Mills, and Northern States Power— have teamed up on the subject. Their object: to determine and act on atomic projects that will benefit Minnesota and its industry. All three companies are already active in the field. Both Honeywell and General Mills, of course, accent the automatic control approach. So keep your eye on Minnesota Nuclear Operations Group.

Atom Biz In Tiz

Formerly unobtrusive nuclear experts are buying their first loud neckties. During Dec. 12-16 they'll trudge through Cleveland's spacious Public Auditorium to take in the first Atomic Exposition—sponsored by the American Institute of Chemical Engineers and a host of other societies. Oh, yes. It's not all hardware and handshakes. There will be 200 technical papers at 50 sessions. None of this material will duplicate the program at Geneva this summer (see above).

COMPUTER ROUND-UP

Hays Buys Metrotype

With a clear eye on its future, The Hays Corp. recently made an outright purchase of Metrotype Corp. of Summit, Ill. Metrotype's digital recording equipment and line load control systems are a natural adjunct to Hays' line of power process controls. George Foster will continue as Metrotype president, and Ed Corson, Jr., stays on as V.P. There will be no merging of manufacturing.

Program Speeders—by Leaders

The two giants of the digital business—Sperry Rand Corp. and IBM—have been investing considerable engineering talent in the knotty problem of automatizing computer programming.

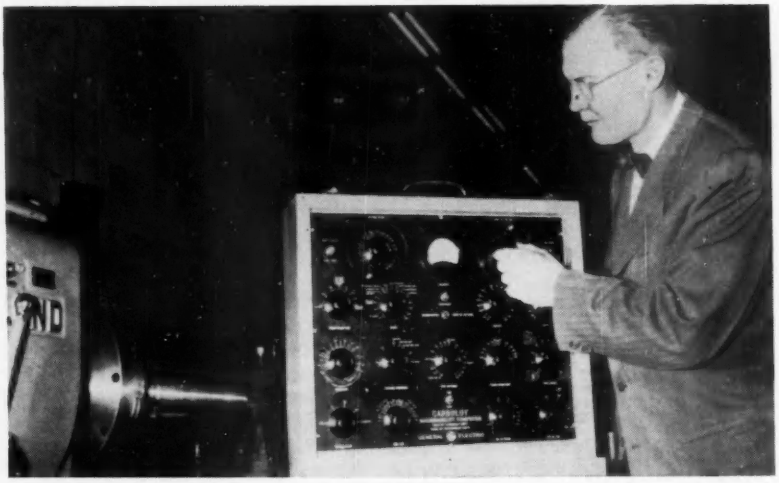
Early in June Sperry Rand ran up a victorious flag. It announced three new steps in automatic programming. The first is *Generalized Programming*, a compiling system for the trained programmer familiar with UNIVAC code. The second is *BIOR*, Business Input-Output-Rerun, a system that involves some word specification before the computer takes over and compiles and organizes the program. And, finally, *B-zero*, the company's nearest approach to automatic programming. *B-zero* requires no familiarity with UNIVAC. It accepts mathematical notes or plain English and will automatically produce the needed UNIVAC program. Extra instructions, such as editing and rerun procedures, can be added to this compiler to integrate into existing routines or subroutines.

Meanwhile, IBM has sped along on its own program. Last fall, in a series of industry seminars, it collected the prescription for *Fortran*—IBM Mathematical Formula Translating System. No official word has come out, but *Fortran* is known to be highly successful as an automatic programmer for the company's line of scientific binary computers (the 704 type). IBM claims that it eliminates all manual coding and plugging, thus reducing programming time by 50 per cent.

IBM people are much more secretive about an automatic programming system for the family of decimal type computers (702, 705). The only thing definitely known: it's in the works.

Flow Group Gripes Grasped

Analog computers will be stellar performers at the forthcoming National Conference on Industrial Hydraulics, Chicago, Oct. 27-28. They'll be put on stage during the big general session to solve some of the audience's most trying hydraulic problems. Besides the demonstration, there will be papers on computer applications delivered by H. M. Martinez of Berkeley Div., Beckman Instruments; J. R. Strong of Electronic Associates, Inc., and Prof. J. A. Hrones, Director of MIT's Dynamic Analysis Laboratory.



COMPUTES MACHINING PROBLEMS: Dr. W. W. Gilbert of General Electric's Mfg. Services Div. is shown with the unique analog computer he developed. It can evaluate up to 13 variables and come up with an optimum machine setting. The computer will be made by GE's Instrument Div. and sold by the Carboloy Dept. in Detroit.

can you use this

high-stability constant voltage source?

Here is a tubeless constant voltage source which can replace the chemical cell and gas VR tube in many types of measurement and control circuits.

We call it the "k-Volt Standard" . . . and we use it to provide the critical reference voltage in our jet aircraft Temperature Indication Systems. Its characteristics make it equally applicable to laboratory, process, control and computing instrumentation . . . as a voltage standard, a constant output working supply, or a precision voltage regulator.

For example:

It can provide any specified output up to 6 volts.

Output is constant within 0.05% over a 20% variation in line voltage . . . within 0.2% through ambient temperatures from −55C to +70C.

Current drain can be as high as 11 ma.

About the size of a vacuum tube, it is hermetically sealed and plugs into a standard tube socket.

It is unaffected by position, vibration or mechanical shock.

Most important . . . these characteristics can be readily modified to meet your own specific requirements.

AVIEN

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Precision Instruments and Control Systems

If you have an application for the "k-Volt Standard", send in the form below, telling us your requirements. We believe the "k-Volt Standard" will be able to meet them, with important advantages in cost, performance and reliability.

The k-Volt Standard . . . Avien's high precision constant voltage source . . . is designed to meet rigorous military specifications. We believe it can meet your specifications, too. Send coupon now with your design and performance requirements.

Market Research Dept. AVIEN, INC., 58-15 Northern Blvd., Woodside, 77, N. Y.

We have an application for your k-Volt Standard, with the following design and performance requirements:

Application: _____

_____

DC Output: Volts _____ Current _____

Input Source: DC Volts _____ AC Volts _____ AC Freq. _____

Ambient Temperatures _____

Temperature Coefficient _____

Connections: Plug in: 7 pin _____ 8 pin _____ 9 pin _____

Solder Lug _____ Threaded Stud _____

Pigtail _____ Other _____

Case: Hermetic Seal _____ Gasket Seal _____

Uncased _____ Potted _____

Other _____

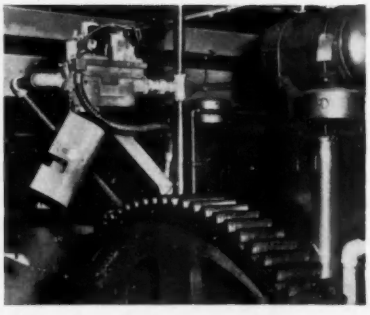
Other Requirements _____

Name _____ Position _____

Company _____

Address _____

Control Safeguards You: ON HIGHWAY, IN PLANT, ALOFT, and in the woods



IN PLANT of Clark Controller the company tests its new feedback actuated protector valve on the "world's safest" air clutch press.

ALOFT there will be a new sense of direction as this Kollsman photoelectric sextant infallibly tracks the sun and the stars.

Last month control engineers seemed more preoccupied with safety than with speed and precision.

Take the thoughtful designers at Clark Controller Co. For years they had been improving safety features in the company's line of controls, making stamping press accidents almost as rare as the Dodo. But they wanted to wipe out the danger completely. Recently they hitched up a very special anti-repeat control to their own plant's busy air-clutch press and enhanced it with a new doubly-safe protector valve. The "very special" part of the project: transistors instead of relays. So now their supersafe press is a guinea pig to demonstrate both transistor reliability and reduced press downtime. You can bet this pioneering application of transistors will be watched.

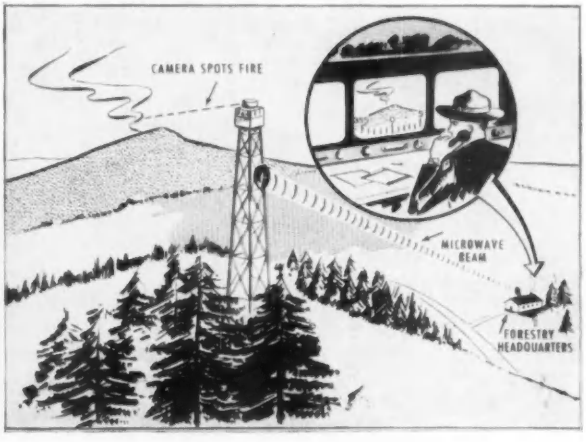
True, control may make the plant safe, but what about after you leave it at 5 p. m. for that harrowing drive home? Here, too, some thoughtful engineers have been at work. Looking earthward for a while, a group at North American Aviation figured that air traffic control could be applied to some of the more jet-like ground vehicles. Like fire-engines, for instance. So they came up with a neat little transmitter to perch on the truck windshield. As the red engine clangs towards crowded intersections this transmitter will trip oncoming red lights. A recent swoop test through busy Pico Boulevard and Figueroa Street in Los Angeles proved the boys weren't off in the clouds on this one.

But there is still danger in the clouds, too. Especially when an aircraft navigator, rusty in his art, discovers the clouds won't cooperate to give him a star or sun fix. But score another for the safety men. Kollsman has perfected the first automatic sextant for aerial navigation. It uses a photo-sensitive telescope to sweep and track an astral body. And it will bird-dog despite wind, slip, and changes of course. You'll always get home now—no more "deadhead" reckoning.

Finally, you get away from machines, motors, and slippery bathtubs, and go off to the woods for peace and safety. But are you safe? Many is the weekend woodsman who's yearned for the city when faced with an onrushing forest fire. So thank Raytheon for taking care of this poser. It put its TV and telemetering know-how together in a remote sweep camera network that microwaves its findings into a central fire watch station.

ON THE HIGHWAY North American's remote red light actuator, carried by speeding fire trucks, will guarantee your safety.

AND IN THE WOODS you'll be safe from raging forest fires, pinpointed in infancy by Raytheon's new system.



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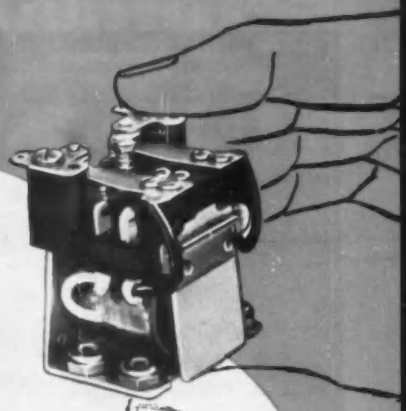
HIGH QUALITY, GENERAL-PURPOSE RELAYS FEATURING COMPACTNESS, DEPENDABILITY AND LONG LIFE!



hermetically sealed or dust-protective enclosures

48 TYPES available from **STOCK**

Current ratings up to 25 amp, AC or DC

When you want the utmost in relay dependability, investigate the Amrecon line. Amrecon relays are designed, produced, and tested in the new, air-conditioned Ohmite plant.

These ruggedly built relays have the ability to handle power loads usually requiring larger, heavier units. They are built to meet rigorous aircraft relay standards, and are particularly adapted to mobile equipment where severe shock and vibration are encountered.

Amrecon relays are available with screw, plug, or solder-wire terminals; in a variety of contact arrangements; with hermetically sealed or dust-protective enclosures. Order from the 48 stock types, or let Amrecon's engineers help you work out special relay applications.

Send for Catalog R-10

OHMITE®
MANUFACTURING COMPANY
3674 Howard St., Skokie, Illinois (Suburb of Chicago)

Miniature Pressure Transducers

STATHAM UNBONDED STRAIN GAGE TRANSDUCTION

MINIMUM RESPONSE TO VIBRATION OR ACCELERATION

TEMPERATURE COMPENSATION OVER 315° F. INTERVAL

20 MILLIVOLTS AT 5 VOLT EXCITATION

PRESSURE ADAPTERS FOR CLOSED LINE APPLICATIONS

HOMOGENEOUS SENSING DIAPHRAGM SURFACE

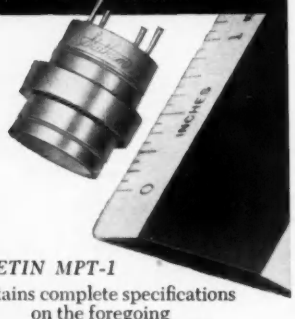
NO EPOXY RESIN PRESSURE SEALS

MAXIMUM LINEARITY

ABSOLUTE PRESSURE
0-5 to 0-150 PSIA . . . MODEL P130

DIFFERENTIAL PRESSURE
±2.5 to ±25 and 0-5 to 0-150 PSID . . . MODEL P131

GAGE PRESSURE
0-5 to 0-150 PSIG . . . MODEL P132



BULLETIN MPT-1
contains complete specifications on the foregoing pressure transducer models.

All matters pertaining to sale or use of instruments of our manufacture are handled by engineering personnel directly from our Los Angeles plant.

Please feel free to wire or telephone us collect whenever we may be of service.

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WHAT'S NEW

FRONTIER INSTRUMENTS: Enterprising members of the Niagara Frontier Section of ISA got together and cooked up this very active instrument show in Buffalo's Erie County Technical Institute. There were 48 exhibitors, mostly national.

INSTITUTIONAL DOINGS

Transistors vs Tubes

Highlight of the recent Electronics Components Conference (sponsored by IRE, AIEE, RTMA, and WCEMA in Los Angeles, May 26-27) was a spirited after-dinner debate on whether or not "Transistors will soon replace most tubes." Over 700 packed into the Cocoanut Grove to hear Dr. Simon Ramo (Ramo-Wooldridge Corp.) advise the contestants to "abandon for one evening their usual inclination to present a highly balanced and objective discussion." And, my! Did they abandon! Some sample quotes:

▶Dr. Louis Ridenour (International Telemetering): "The electronic tube is a monstrous and improbable device that burns out quickly."

▶Dr. W. R. Baker (General Electric): "Tube costs will be reduced by use of automation in manufacturing."

▶Dr. Harper Q. North (Pacific Semiconductors): "The cost of transistors is going down so rapidly that there might be a period of temporary overshoot in which manufacturers would pay users to take transistors."

▶Maj. Gen. C. S. Irvine (Air Materiel Command); "Transistors are like a new baby that has just learned to say 'goo'."

At the end of the contest the applause meter (using vacuum tubes) favored the anti-tube faction. But a visiting debating professor's report stated that "both sides showed complete lack of timidity, failed to get to the point, contradicted themselves, and frequently agreed with the opposition." He gave the negative fewer demerits. Dr. Ramo called the results "debatable".

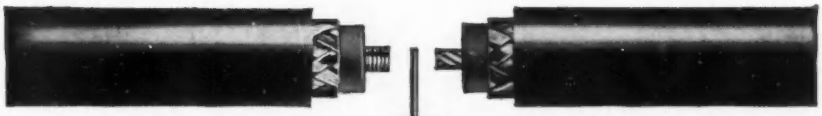
The hot tempo of the debate continued on the dance floor, over-riding sultry rhumba tempos provided by Xavier Cugat. Many wives, whirled by their still-stimulated husbands, stated they had "learned things from the debate their husbands never tell them."—E. M. GRABBE.

RPI Furthers Mag Amps

When a certain group of fifteen graduate students leaves Rensselaer Polytechnic Institute, they'll be well-primed on the fundamentals and future of magnetic amplifiers. They took the unique course under Dr. Herbert F. Storm, guest specialist from General Electric and author of a text on the subject. Part of their work included diagramming the functions of mag amps in servo systems. RPI's pioneering may soon pay off as a visible boost to the control field.

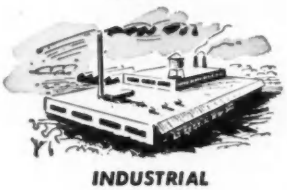
Advanced Control at Harvard

Starting next fall, Harvard University will offer graduate courses lead-



AVIATION

MARINE



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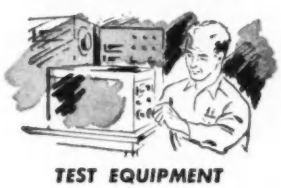
RADIO-TV LEAD-INS



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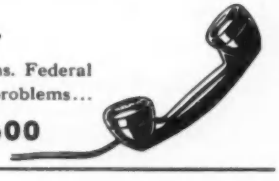

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DOELCAM Microsyn Position Indicators are small electromechanical signal generators which transform angular displacement into an electrical signal. Their high accuracy and dependability offer a new level of instrument performance to designers of indicating and control equipment in the chemical, refinery and process industries. Write for Bulletin MP 34

Type 1C-020 MODEL	A	B	C	D	E	F
Frequency cps	60	400	400	400	1000	5000
Excitation volts	6.3	10	26	55	10	10
Excitation ma	26	45	37	23	44	38
Sensitivity 100k load v/degree	0.27	2.01	2.88	3.00	3.81	3.07

- Linearity ±½% to 7 degrees, ±1% to 10 degrees.
- Residual Null Will not exceed signal equivalent to 0.01 degree rotation.
- Static Friction Standard Model 0.03 oz.-in. Low Friction Model 0.002 oz.-in.
- Reaction Torque Less than bearing friction level.
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ing to advanced degrees in Control Systems Engineering. To get his master's a student will have to complete eight half courses, selected with faculty approval. Some examples: Servomechanisms and Feedback Systems; Simulation and Synthesis of Systems; Timing Circuits and Pulse Techniques; Theory of Switching; Dynamics of Machinery.

The prospective PhD must spend a minimum of two years in residence and develop a thesis describing original research in control engineering. Full details are given in a handsome booklet, available from the Dean of the Graduate School, 24 Quincy Street, Cambridge 38, Mass.

Gas Measurement Curricula

The 15th annual gas measurement short course will be held at West Virginia University, Morgantown, Aug. 29-31. This year more than 700 control engineers—mainly from utilities firms—are expected to bone up on new developments in metering, monitoring, and controlling fuel. Nearly 100 teachers are borrowed from industry to conduct the classes and laboratory sessions.

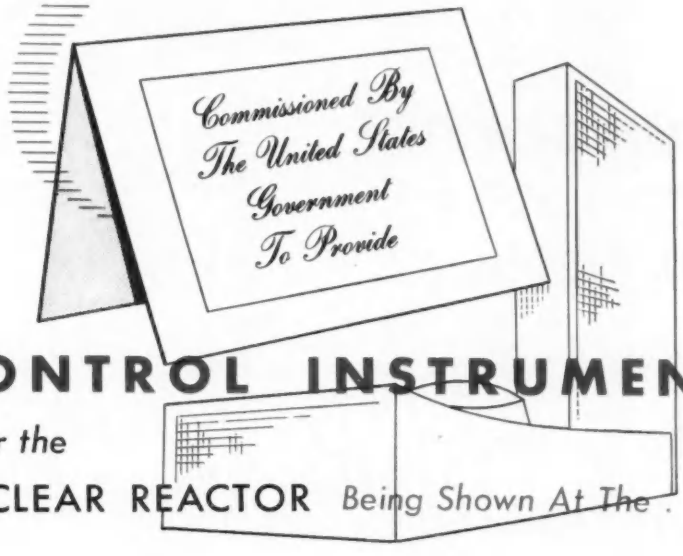
Eight Institutes to Display Control for the Future

About 100,000 production engineers and executives from manufacturing plants in this country and abroad soon will be able to sample personally the flourishing academic side of control engineering. The occasion: Chicago's Production Engineering Show, to be held on the Navy Pier, Sept. 6-16, in conjunction with the famous Machine Tool Show in progress at the same time in the Stockyard Amphitheatre. The special control project: a visual display of university research in automatic techniques, to be manned by a staff of university men in a 2,500 sq ft area.

The eight institutions that will pluck the fruit of control research from their graduate student workbenches are Case, Cornell, Illinois Tech, Illinois, MIT, Michigan, Northwestern, and Ohio State. Some of their displays—

- ▶ a hydraulic analog computer to study air conditioning loads
- ▶ automatic control for an iron lung based on patient feedback
- ▶ control techniques for high speed

DAYSTROM INSTRUMENT

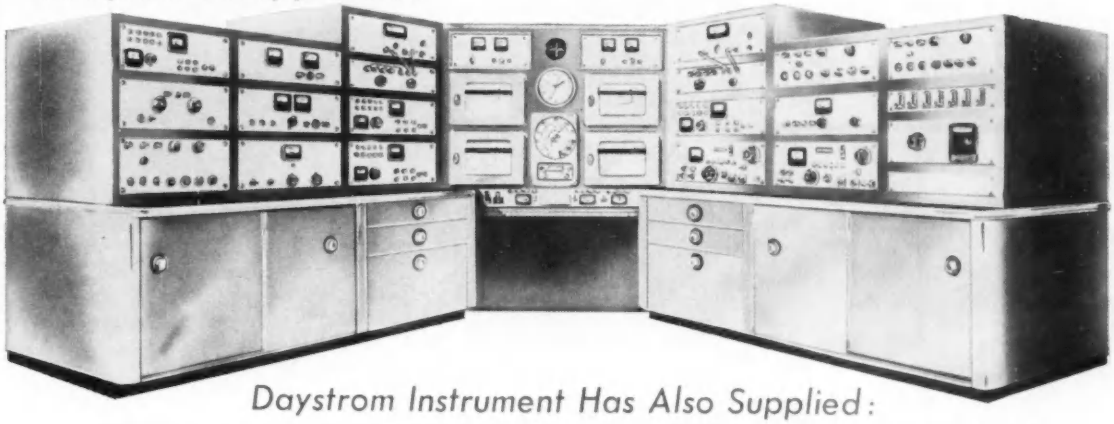


CONTROL INSTRUMENTATION

for the NUCLEAR REACTOR *Being Shown At The . . .* UNESCO CONFERENCE

Geneva, Switzerland

DAYSTROM INSTRUMENT is in full scale production of nuclear instruments for the Atomic Energy Commission and industry . . . and has the facilities, "know-how" and skilled manpower to supply control instruments tailored to your requirements. You can look to Daystrom for instruments of finest quality, utmost precision and top performance.



Daystrom Instrument Has Also Supplied:

Control instruments, computing mechanisms, test equipment for all branches of the Armed Services . . . and many of America's leading industrial concerns—as well as foreign companies.

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Capacitance Testers, All-Altitude Servo Indicators, Transistorized Receivers, R F Switches.

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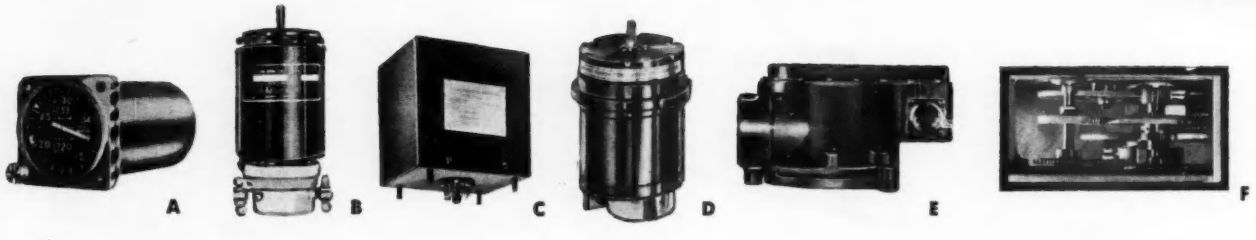

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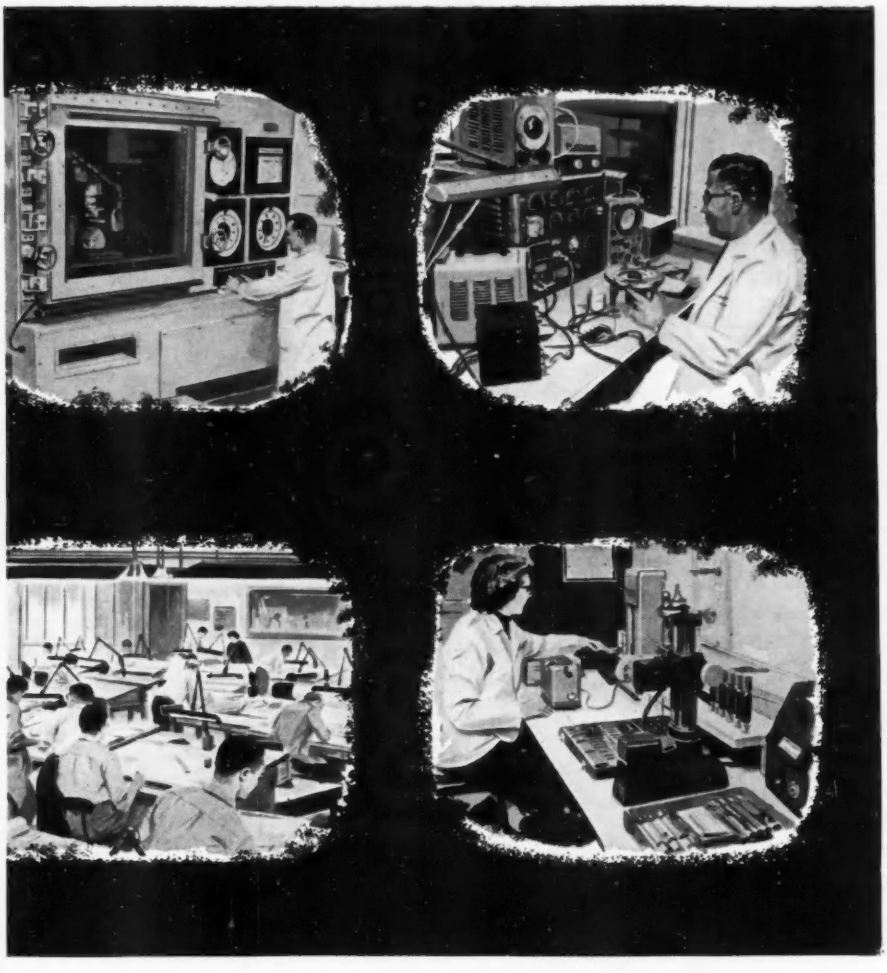
Vari-ohm Corp., Amityville, Long Island, N. Y.
Scientific Specialties Corporation, Boston, Mass.



A...Jet Engine Pressure Ratio Systems. Noted for low weight, small size, accuracy, stability, sensitivity. Refer to Bulletin #361.

B...Digital Converter. Possible rate of 25,000 counts per minute, an unambiguous output of 13 binary digits in natural binary code. Refer to Bulletin #360.

C...Magnetic and Electronic Amplifiers. Open, dust-proof or hermetically sealed units. Either standard or to customer specifications. Write for specific data.

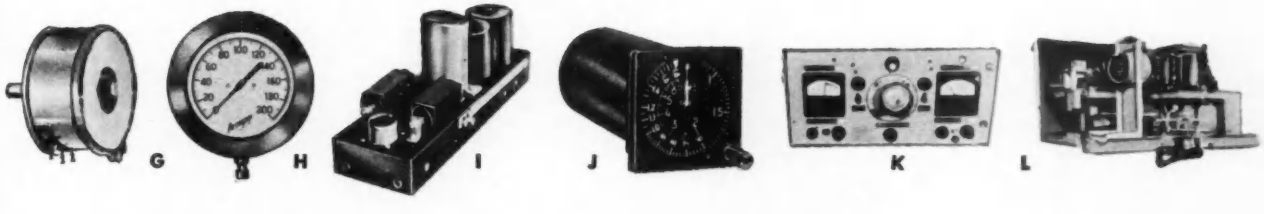
D...Synchros, Servo Motors and Resolvers. Specifications and characteristics of over 130 sizes and types are given in Bulletin #355.

E...Fuel Flow Transmitters. Major instruments, components, and systems for aircraft are available. Write for specific data.

F...Gear Trains. Conventional and miniaturized types for use with servo motors and synchros.

G...Potentiometers. Linear and non-linear, ten-turn potentiometers, single-turn continuous units and others are described in Bulletin #321.

H...Acragage Bourdon Tube Gauges. Pressure, vacuum and compound for the petroleum, chemical, and industrial field. AN types for aircraft. Refer to Bulletin #364.



I...Servomechanisms. Made to meet extremes of temperature, humidity, and special configuration. Submit your requirements.

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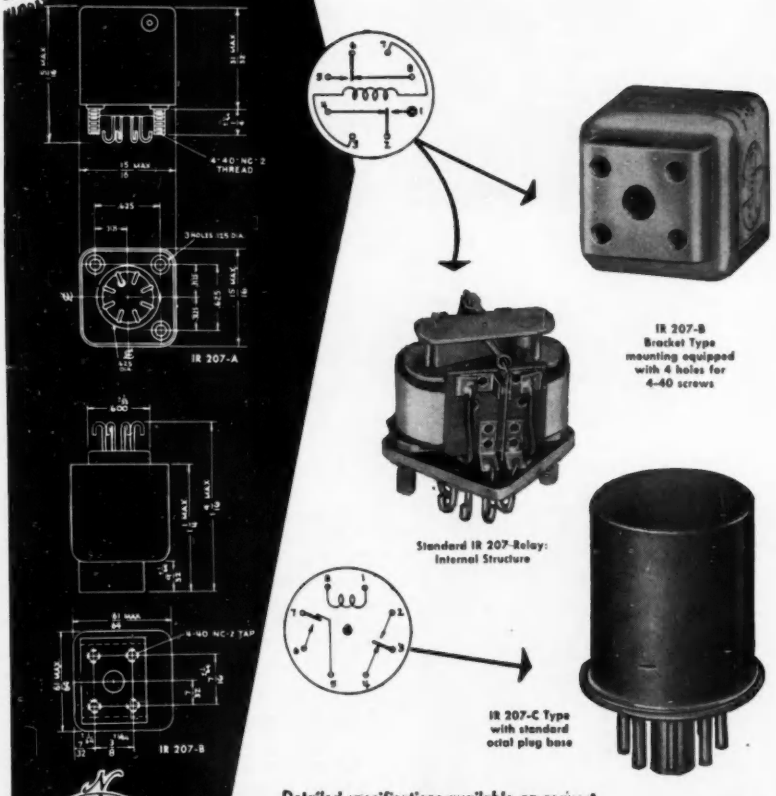
ROTARY ARMATURE

IR 207 RELAYS by NORTH

A subminiature rotary armature relay designed for a variety of airborne and guided missile applications where *reliable* operation in severe environment is required.

1. **Two form C contacts rated at 2 amps, 30 volts, DC resistive.**
2. **Low capacity between contacts and ground.**
3. **The standard IR 207 relay meets the reliability requirements under MIL-R-5757B.**
4. **For critical applications where more reliability is required than is provided under MIL-R-5757B, North's "Special *High* Reliability" hermetically *sealed* relays are now available.**


IR 207-A
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Bracket Type mounting equipped with 4 holes for 4-40 screws
Standard IR 207-Relay: Internal Structure
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Originators of ALL RELAY Systems of Automatic Switching

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WHAT'S NEW

metal cutting

- a "random programmer" for statistical production sample selection
- an optimizing servo automatically controlling a flame
- an advanced punch tape control for milling machines
- a new approach in fluid density measurement

The idea for the unprecedented university exhibit originated during a meeting of McGraw-Hill's CONTROL ENGINEERING, PRODUCT ENGINEERING, and AMERICAN MACHINIST with Capp & Poliak, the managers of the exposition. C & P generously donated financial support. McGraw-Hill took over sponsorship of the exhibit. And CONTROL ENGINEERING editors went into the field to roundup displays (see *Shoptalk*).

Around the Business Loop

- Recognition of the need for skilled technicians to service industrial instruments was reflected in the number of these men, as compared to the number of salesmen, who were turned out by the 47th Industrial Div. training school of **Minneapolis-Honeywell Regulator Co.** in Philadelphia. The 27 engineers and nine salesmen have been assigned to branch offices in 27 cities in the U. S., Canada, and Germany.
- **Servomechanisms, Inc.**, has divided its executive offices between Westbury, N. Y., and Hawthorne, Calif., locations, respectively, of its Eastern and Western Divs. The move from Garden City, N. Y., was in line with a current program to coordinate the two divisions.
- As a logical follow-up to its expanded manufacturing and service facilities, **The Foxboro Co.** has established ten regional sales divisions in New England, New York, Philadelphia, Pittsburgh, Atlanta, Cleveland, Chicago, Dallas, Houston, and San Francisco. H. O. Ehrisman, general sales manager, and J. J. Burnett, field sales manager, both recently appointed (see *What's New*, June, 1955), will administer the new territories.
- Work with powder camera techniques and the X-ray diffractometer and spectrograph will comprise the curriculum for the 21st and 22nd sessions of the Norelco X-ray diffraction school, sponsored by the Research & Control Div. of **North American**

Here's An Unbeatable Combination For Displacement Type Liquid Level Control!

It's The BS&B Type 888 Liquid Level Controller With The Type 1450 Liquid Level Control Pilot!

Used Throughout The Refining, Chemical, Power And Special Products Industries!

- ✓ Torsion tube assembly eliminates objectionable packing glands and pressure type bearings.
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- ✓ Control Pilot opens from left or right, as convenient.
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For Better Regulation of Pressures, Temperatures, Liquid Levels or Flow, Equip Your Process With BS&B AUTOMATIC CONTROLS and SAFETY HEADS!

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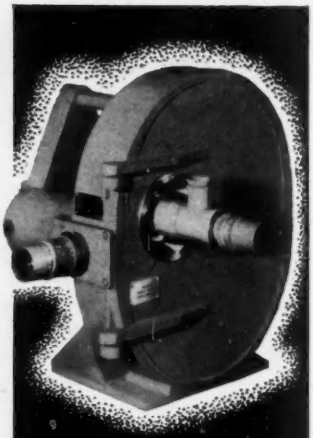
NEW

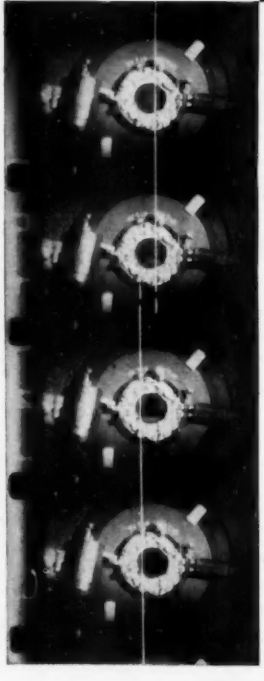
Wollensak

FASTAX

High-Speed Cine-Oscillographic Cameras



8 mm - 16 mm Cameras with 400 ft. capacity ... speed ranges from 500 to 18,000 pictures per second.



With the new combination cine and oscillographic camera there is a simultaneous recording of visual and electrical phenomena. The oscilloscopic image is superimposed over the motion picture image on the emulsion side of the film. Thus a permanent record is available for study and measurement.

New features:

- Lenses in focusing mount with bayonet attachment.
- Through-the-lens viewing and focusing finder for both "oscillo" and motion picture.
- Improved rotating prism for sharper images.
- Can be used either as a high-speed motion picture, streak or combination camera.

WRITE for more detailed information and prices.

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OPTICAL COMPANY
850 Hudson Ave., Rochester 21, N.Y.

WHAT'S NEW

Philips Co. The sessions will be held Sept. 26-30 in San Francisco, and Oct. 10-14 in Chicago. There is no registration fee.

► Two American manufacturers of automatic control equipment have appointed the same service and sales representatives in Canada. The manufacturers: **ElectroData Corp.** and **Mid-Century Instrumatic Corp.** The representative: **Data Processing Associates, Ltd.**, of Ottawa, which specializes in the application of analog and digital computer techniques and holds several other sales franchises, mostly of

George S. Glinski

Douglas H. Peacock

Canadian electronics firms. President of DPA is George S. Glinski, and vice-president and managing director is Douglas H. Peacock.

Among recent expansions, mergers, and births:

► **Nuclear Magnetics Corp.**, a new subsidiary of **The Perkin-Elmer Corp.** Offices will be in Boston and Norwalk, Conn. Nuclear Magnetics, which has purchased the NUMAR line of nuclear magnetic resonance equipment from **Laboratory of Electronics, Inc.**, can claim some of the top nuclear magnetics men as consultants: E. M. Purcell and Robert V. Pound of Harvard; Francis Bitter of MIT; and Rex Richards of Lincoln College, Oxford, England. A. Carl Westbom, Jr., and Marvin C. Lewis, formerly with Laboratory of Electronics, join the new corporation as technical director and sales manager, respectively.

► **Avron Corp.** into **Clary Corp.** Avron's President Roy Moore and Vice-president Brian Sparks will continue to supervise manufacture of their corporation's aircraft valves and pressure regulators, which will be produced at Clary's main plant in San Gabriel, Calif.

► **Ideal Laboratory Tool & Supply Co.** of Cheyenne, Wyo., and **Aerosmith Instrument Co.** of Hawthorne, Calif., into **Ideal-Aerosmith.** Ideal's pressure instrument and rate-of-motion equipment, and Aerosmith's aircraft instruments will be produced, in the main, in Hawthorne, although both com-

panies will continue to operate separately. Among the officers: Robert M. Tinus, chairman; C. Cortland Smith, president; Dennis E. Frisbie, executive vice-president; and Donald D. Kallenbach and C. Joseph Brewer, vice-presidents.

► **Autron Engineering, Inc.**, a new Los Angeles manufacturer and designer of automatic control equipment. President is Robert E. Poole, Jr., formerly project engineer of **Stavid Engineering Co.**

► **Technology Instrument Corp. of California** has expanded into a new plant in North Hollywood. Facilities now exist for manufacture, assembly, testing, and inspection of precision potentiometers, and for complete servicing of all TIC laboratory instruments.

► **Sanders Associates, Inc.**, has purchased the 500,000 sq ft plant in Nashua, N. H., that it has tenanted for several years.

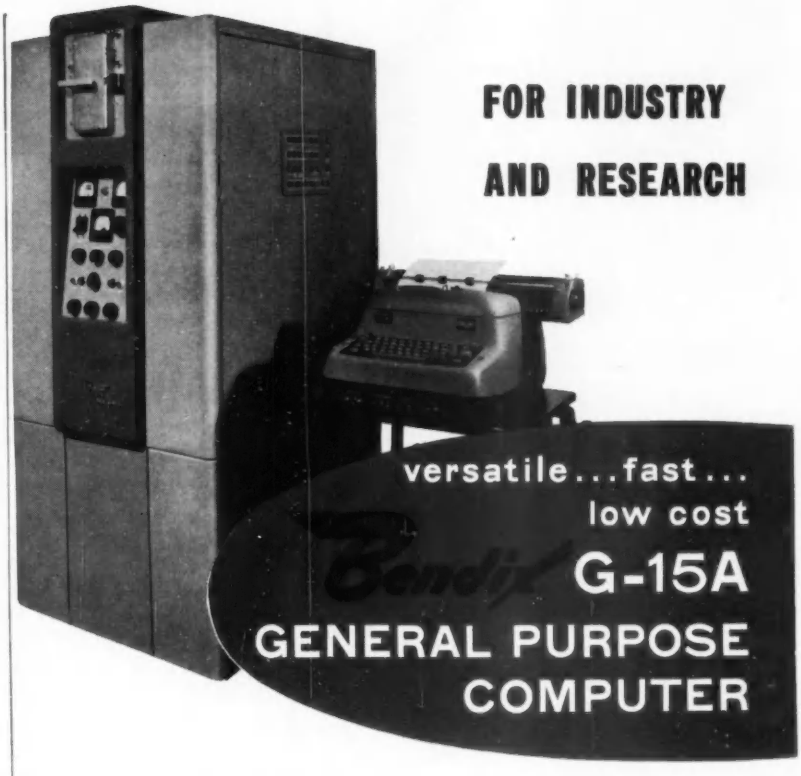
► **Aerovox Corp.** has succeeded the **Kaiser Electronics Div.** of **Willys Motors, Inc.**, as operator of the **National Bureau of Standard's** pilot plant for the mechanized production of electronic equipment. Manufacture will continue in Arlington, Va. Key personnel of the Willys division have hired on at Aerovox, which will emphasize production of modules for experimental use by interested electronic equipment makers. This is "Project Tinkertoy", developed by NBS for the Navy.

► **Taylor Instrument Co.** has moved its western regional sales headquarters and branch assembly plant from San Francisco to an area four times as large in San Leandro, Calif.

Important Moves by Key People

► Convair Div. of General Dynamics Corp. has shifted several names high on its engineering payroll: **Adolph Burstein,** formerly chief development engineer, becomes assistant chief engineer; **S. G. Frank Hass, Jr.,** formerly chief of preliminary design, becomes chief development engineer; and **Jack L. Bowers, Jack Mason,** and **Dr. Marvin Stern** join the staff of **R. C. Sebold,** vice-president of engineering. Bowers' area will be electronics, Mason's engineering facilities, and Stern's liaison for research problems in military aircraft and missiles.

► **Paul S. Dickey,** who succeeds **Robert S. Coffin** as president of Bailey



The G-15A is a stored program digital computer which performs arithmetic and logical operations at high speed. It incorporates an improved two-address command structure which permits greatly increased flexibility.

The machine is convenient to operate, with all controls centrally located on the electric typewriter. It can be programmed to solve all classes of mathematical problems. The Computer will operate using single or double precision numbers. In addition efficient floating point performance is possible through the use of sub-routines.

The Bendix is one of the lowest priced general purpose computers available. The machine is in production.

The G-15A is unusually compact because of its advanced logical design and occupies only as much space as two filing cabinets.

MAIL THE COUPON TODAY
OR WRITE FOR COMPLETE INFORMATION

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Please send information and prices on your G-15A Computers.

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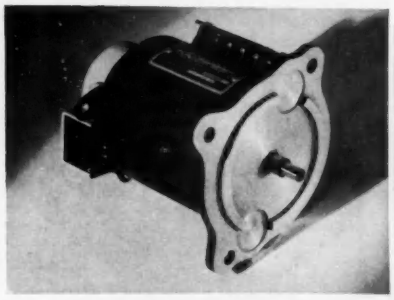

American Electric Model 313

COMBINATION DRIVE MOTOR AND BLOWER BUILT TO USAF SPECIFICATION 32590

This rugged, totally enclosed miniature combination drive motor and blower develops ⅛ hp at 7200 rpm, continuous duty. It operates on 3 phase, 400 cycle current at 200 volts. Teflon insulated for ambient temperature range from −65° C to 112° C. Weighs only 4.2 oz. Approx. overall length 5". Flange dia. 3½".

Many Other Models Fully Developed

American Electric Miniatures are available for operation on 60, 400, 1600, or 2000 c.p.s. or on variable frequencies from 320 to 1200 c.p.s.

TWO TYPES:

INDUCTION—Output torque range from ½ in. oz. to 120 in. oz.

SYNCHRONOUS (Hysteresis or Reluctance Models) Output torque range from .01 in. oz. to 16 in. oz.

Ask for quotations on special requirements!

MODEL 182DA AXIAL FAN MOTOR—Totally enclosed, panel mount, screened intake, high temp. operation 20 CFM N.A.F.M. at free air. O.D. 1.45", 115 V., single phase, 400 cycle, or variable frequency models.

MODEL 430 AIRCRAFT DRIVE MOTOR—1/12 h.p. 11,000 r.p.m. Teflon insulation. −65° F. to +160° F. Completely qualified to MIL 7969 specs.

MODEL 323 ELEVON ACTUATOR—Develops ½ h.p. at 11,200 rpm. 200 V. line-to-line, 3 phase, 4 wire, 400 cycles. Teflon insulated for −65°F. to +160°F. operation. Meets MIL M 7969 specifications.

MODEL 201D HYSTERESIS SYNCHRONOUS MOTOR—For Reference Timing Applications 12,000 r.p.m., 5 to 25 gm. cm. torque. Plain or geared shaft extensions.

FIELD ENGINEERING OFFICES in all major industrial areas in the United States and Canada.

American Electric Motors, Inc.
Miniature Components Division of
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4811 Telegraph Road, Los Angeles 22, California

WHAT'S NEW

Bailey Meter's President F. S. Dickey and Vice-presidents H. H. Gorrie, R. D. Junkin

Meter Co., is one of three former chief engineers affected by recent company changes. The others: **Harvard H. Gorrie,** elected vice-president of engineering, and **Raymond D. Junkins,** elected vice-president and a director. Coffin, president since 1944, becomes chairman of the executive committee and management consultant.

▶Transistor Specialist **Richard B. Hurley** has joined Consolidated Engineering's Research Div. as senior research engineer. Hurley, formerly senior electronics engineer for Convair at Pomona, has written several articles on transistor amplifiers.

▶**A. A. Markson,** who has been in charge of mechanical research and development for Hagan Corp., will assist Vice-president **R. R. Donaldson** in coordinating engineering activities in the mechanical division. His new title: assistant vice-president in charge of engineering. Markson is credited with important spade work in heat transfer through boiler tubing.

▶**Dr. William S. Gallaway** has returned to the Beckman Div. of Beckman Instruments, Inc., as infrared applications superviser. The former member of the division's research and development staff will concentrate on integration of infrared applications with automatic process control instrumentation.

▶**Joseph B. Rice** and **George B. Holmes,** officers of ElectroData Corp., have been promoted, Rice to vice-president-manufacturing, and **Holmes** to assistant treasurer. Rice will continue as assistant secretary. Holmes

Con Engineering's Hurley

Hagan's Markson

Beckman's Gallaway

ElectroData's Rice

Leeds & Northrup's Moat

Industrial Nuc's Van Horne

if you need to **control heat**

it'll pay you to look into

Adlake mercury relays

Adlake relays require no maintenance whatever ...are quiet and chatterless...free from explosion hazard...dust, dirt, moisture and temperature changes can't affect their operation. Mercury-to-mercury contact gives ideal snap action, with no burning, pitting or sticking. Time delay characteristics are fixed and non-adjustable.

Adlake 98th year of serving the transportation and building industries

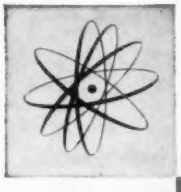
The Adams & Westlake Company
Established 1857 ELKHART, INDIANA • New York • Chicago

the *original* and largest manufacturers of mercury plunger-type relays

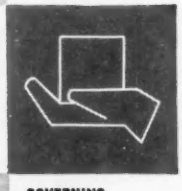
the PRODUCTION ENGINEERING SHOW

SEPTEMBER 6-16, 1955
NAVY PIER, CHICAGO

The Automation Exposition



MONITORING EQUIPMENT
such as: Recording and control equipment. Electronic devices. Switches, relays and electrical components. Counters and computers. Mass spectrometers.



HANDLING EQUIPMENT
such as: Conveyors, Cranes, Hoists, Monorails, Pneumatic tubes. Clamping, rotating and positioning equipment. Loading and unloading equipment.

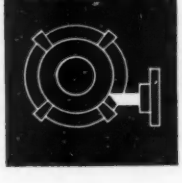
EQUIPMENT COMPONENTS
such as: Air and hydraulic mechanisms. Mechanical activators. Brakes, clutches and other drive mechanisms. Electrical, air and hydraulic motors.

GOVERNING EQUIPMENT
such as: Devices for tramp iron removal. X-ray, fluoroscope and photocell devices. Limit switches and governors.

COMMUNICATIONS EQUIPMENT
such as: 2-way radio. Telephone and paging systems. Teleprinters and facsimile. Industrial television. Special signaling equipment.

INSPECTION AND GAGING EQUIPMENT
such as: Air gages. Strain gages. Beta ray thickness gages. X-ray gages. Optical gaging equipment.

SPECIAL PRODUCTION EQUIPMENT
such as: Continuous heat treating and drying furnaces and ovens. Abrasive blasting and other finishing equipment. Engineered paint systems. Weighing and proportioning equipment.



MACHINE TOOL ACCESSORIES
such as: Bearings, Cutting tools, coolants. Chucks, dies, jigs. Lubrication systems. Portable tools. Power transmission equipment.

An exposition that does something about AUTOMATION. In one place at one time you can *see* the practical things—mechanisms, instruments, controls, handling devices, data processors, hydraulic, electric, mechanical, and pneumatic components—that you can apply *right now* to make your production and processing more automatic.

There's no blue sky about this show. It's been designed for the production function in industry, leveled at the men who must re-engineer production and processing lines *now* to cope with rising costs and hot competition.

There'll be hundreds of exhibits by leading companies. There'll be thousands of technical experts eager to show you how to get more output from your existing plant facilities.

AUTOMATION is here. Today. The things you learn at the Production Engineering Show can go to work for you immediately to cut costs, to improve production performance.

You can see the great MACHINE TOOL SHOW too!

Your registration badge will admit you, at no additional fee, to the world-important Machine Tool Show – the first since 1947 – at the International Amphitheatre, Chicago, concurrent with the Production Engineering Show. Don't miss it! Shuttle buses will run between shows.

See the practical elements of automation that can be applied to your production and processing right now!

PRODUCTION ENGINEERING SHOW

SEPTEMBER 6-16, 1955
NAVY PIER, CHICAGO

The Automation Exposition

Tickets:
To expedite your registration at the Production Engineering Show, write for Rapid Registration Cards to:

Clapp & Poliak, Inc.
Exposition Management, Dept. PES-1,
341 Madison Avenue, New York 17, N. Y.

In today's
atmosphere of new
horizons being
sighted, new frontiers being
pushed back, and everyone
out-pioneering his neighbor, it is
pleasant to find that one of our own
products has stumbled over the threshold
of opportunity, firmly wedging its foot against
the door to a whole new world of applications.
What especially interests us is that the "product",
the AC version of our Series 41 relay, had, until now, lead
a notoriously humdrum sales life. (Oh, it has *had* some perfectly
good uses: e.g., it performed admirably in electric blanket controls. It's
just that AC applications never seemed to fire anyone's imagination very much.)

But returning to the 41's NEW WORLD—and what it means to YOU . . . (1)
commercial development of broad area cadmium sulfide photocells* of hithertofore
unheard of (output 2.5 ma. rms at 50 volts, 2 foot-candles) sensitivity, now
makes possible the construction of greatly simplified, "amplifier-less" AC photoelectric
devices, and (2) the Series 41 is probably the best low cost AC relay available
with sufficient sensitivity (0.10-0.15 VA) for such use. Conceivably, such a
photoelectric control might consist of simply an AC line cord, broad area CdS cell
and a 41. (Of course, if you *want* to fuss around with rectifiers, we have
some capable DC relays for power switching,—but who hasn't?)

At this stage, we know of at least one manufacturer of photoelectric
controls already re-designing his devices along the lines indicated, and we suspect
this signals some sort of beginning. In case you have some ideas, you can get basic
data sheets describing the 41 just by asking. We'll also give you the benefit of what
application experience we've had to date, bearing in mind this *is* a new world.

**for sale elsewhere, not here.*

SIGMA

SIGMA INSTRUMENTS, INC.
69 Pearl Street, So. Braintree, Boston 85, Mass.

WHAT'S NEW

formerly was chief accountant. Both men have had engineering experience.

▶ New assistant director of marketing of Leeds & Northrup is **Donald E. Moat,** who has been district sales manager in Cleveland. Moat, who succeeds the late **L. E. Emerich** as acting head of the department in Philadelphia, was general chairman of the AIEE's national meeting in the fall of 1951.

▶ Industrial Nucleonics Corp. has appointed **William E. Van Horne** assistant sales manager. Van Horne, who will assist **Henry R. Chope,** vice president and sales manager, joined IN as sales engineer, a title he previously held with the Brown Instrument Div. of Minneapolis-Honeywell Regulator Co.

▶ Clark Controller Co. has named **Ben H. Carlisle,** formerly in the Applied Engineering Dept., manager of its recently established New Products Div.

▶ Design of General Electric's gaseous discharge power control tubes, vacuum rectifiers and power tubes, and camera storage tubes will be supervised by **Harry L. Thorson,** appointed manager of transmitting tube product engineering for the company's Power Tube Sub-Dept.

▶ Guiding development, manufacture, and sale of the digital computer, ALWAC III, will be the first stage in a new program to exploit the potentialities of Logistics Research, Inc. Logistics has brought in a truly "big gun" who, as president and chairman, will direct the program. He is **Sir Robert Alexander Watson-Watt,** discoverer and developer of radar and inventor of the High Frequency Radio Direction Finder ("Huff-Duff").

▶ A Costa Rican physicist at Baird Associates, Inc., has been appointed by his government as its official representative to the International Conference on Peaceful Uses of Atomic Energy, which will be held Aug. 8-20 at Geneva, Switzerland. He is **Anthony Quesada,** a member of Baird's research and development staff.

▶ **Charles Kuhn,** formerly general manager of Fansteel Metallurgical Corp., now is assistant sales manager of the Product Div. of Hills-McCanna Co. He has held engineering posts with Electronic Laboratories and RCA.

▶ **Arthur Wetter,** formerly an electronics engineer with the Civil Aeronautics Administration, has joined the Data Processing Div. of the National Bureau of Standards. The di-

NEW! ASHCROFT 2½" GAUGE

HAS TYPE 316 STAINLESS STEEL SYSTEM TO WITHSTAND CORROSIVE CONDITIONS

High resistance to corrosion and sustained high accuracy are combined in this new heavy-duty Ashcroft Gauge. The 2½" dial size makes this compact instrument ideal for small tanks and processing equipment where large pressure gauges would be impractical. Bourdon tube (welded at socket and tip) . . . square shank and ¼" male N.P.T. bottom connection . . . geared movement—the entire gauge system is Type 316 stainless steel.

Made in standard graduations from 30 psi through 1,000 psi, this new Ashcroft Pressure Gauge has a black dial with easy-to-read white figures. The drawn steel case and threaded ring are finished in black. Pointer is precision needle type. Every part is designed, tested and manufactured to meet rigid service conditions.

YOUR INDUSTRIAL SUPPLY DISTRIBUTOR now has this new Ashcroft Gauge in stock. Let him know your requirements. You can depend on him for experienced counsel and prompt delivery.

In Canada: Manning, Maxwell & Moore of Canada, Ltd., Galt, Ontario

1850 ASHCROFT U.S.A.

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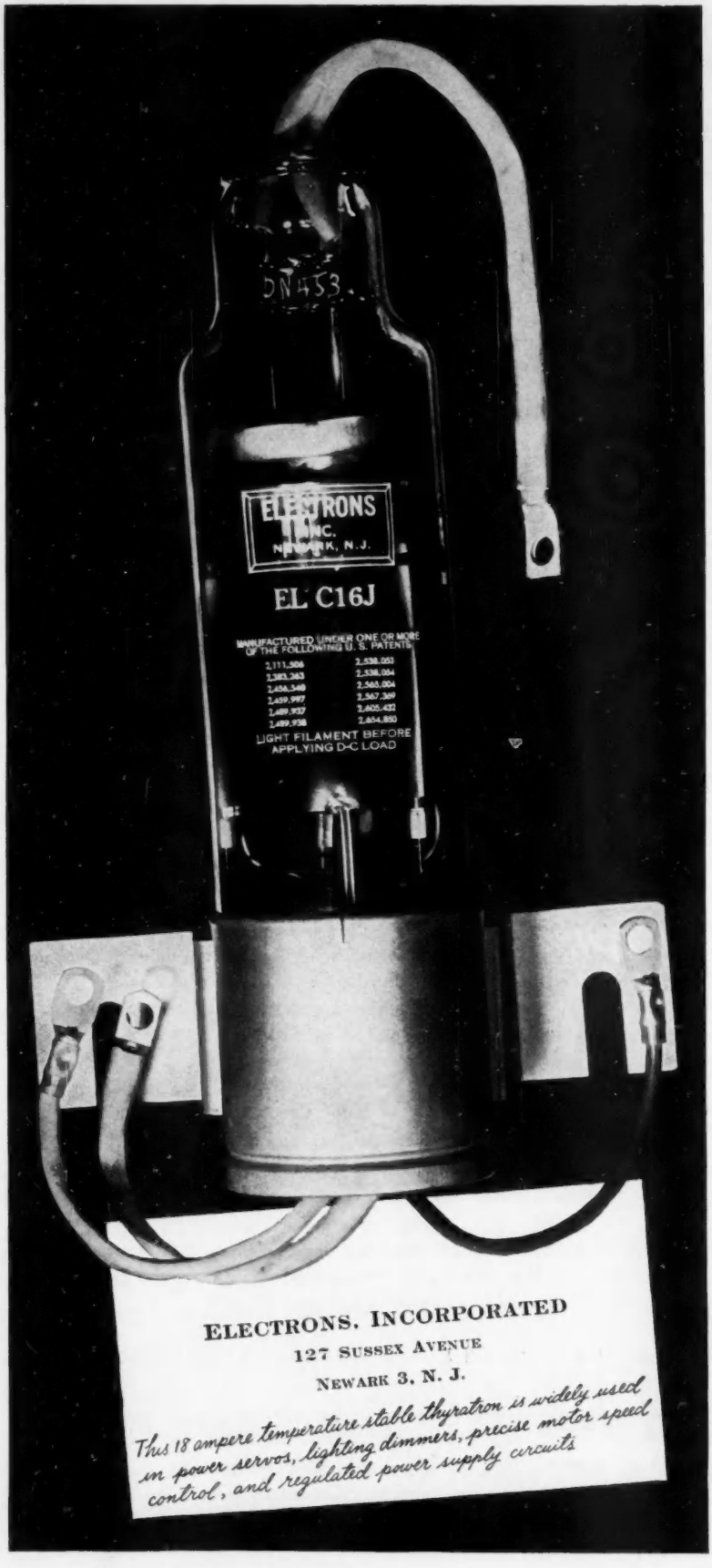
ASHCROFT GAUGES

A product of **MANNING, MAXWELL & MOORE, INC.** STRATFORD, CONNECTICUT

MAKERS OF 'AMERICAN' INDUSTRIAL INSTRUMENTS, 'CONSOLIDATED' SAFETY AND RELIEF VALVES, 'AMERICAN-MICROSEN' INDUSTRIAL ELECTRONIC INSTRUMENTS, *Stratford, Conn.* 'HANCOCK' VALVES, *Watertown, Mass.* 'CONSOLIDATED' SAFETY RELIEF VALVES, *Tulsa, Oklahoma.* AIRCRAFT CONTROL PRODUCTS, *Danbury & Stratford, Conn. and Inglewood, Calif.* "SHAW-BOX" AND 'LOAD LIFTER' CRANES, 'BUDGIT' AND 'LOAD LIFTER' HOISTS AND OTHER LIFTING SPECIALTIES, *Muskegon, Mich.*



WHAT'S NEW

vision has made several exemplary contributions to computer technology.

▶ Ford Instrument's **George H. Compton,** assistant to the vice-president, has been "loaned" to the Department of Commerce's Business & Defense Services Administration. For about six months Compton will serve without compensation as a consultant on synchros and servos to the administration's Electrical Equipment Div. This is in line with the government's practice of borrowing industry men for business and defense programs.

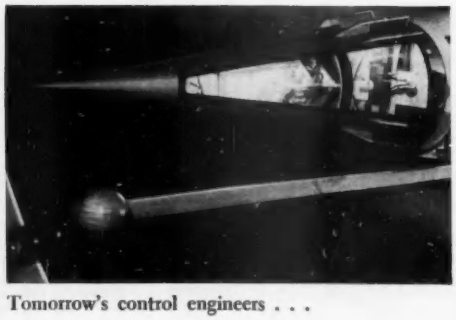
▶ **Rodney D. Chipp** has been named director of engineering for all manufacturing divisions of Du Mont Laboratories, Inc. Former engineering director of the Du Mont Television Network, he'll coordinate the Television Receiver, Cathode-ray Tube, Communication Products, Instrument, and Government Divs., and will be liaison man between divisional engineering departments and the research labs. Chipp's wife, professionally known as **Beatrice Hicks,** is an engineer in her own right.

▶ **I. L. Ashkenas** has left Northrop Aircraft, where he has been chief of the Aerodynamics Dept., to become chief engineer of Control Specialists, Inc., of Inglewood, Calif. Control Specialists has taken on another former Northrop man as vice-president. He is **A. P. Henry,** who also has been with Ford Instrument Co. and Hughes Aircraft.

• • •

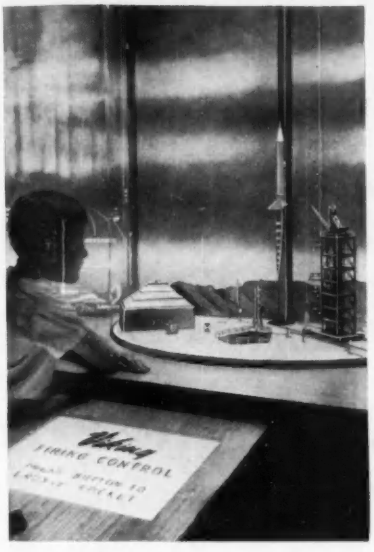
Viking Rocket Goes On Display

On June 30 over 300 scientists, engineers, and press members clustered under the hushed, starry dome of New York's Hayden Planetarium at the official dedication of Viking Rocket Hall. In the hall, which is adjacent to the Planetarium in the American Museum,



Tomorrow's control engineers . . .

Will he be abroad in 1975?



was a full-sized Viking rocket and its instrumentation. But even more dramatic were the bold implications of this meeting: the practical start of a new era, the coming-of-age of rocketry.

Museum Trustee Thomas J. Watson, Jr. (president of IBM) declared that the exhibit of "dizzying" progress would "interpret the findings of these scientists to the public". Naval Research Lab's Milton Rosen told of the work of the naval research and Glenn L. Martin engineers, who created the Viking and nursed it through its eleven firings from the hot sands of New Mexico. And Martin's president, George M. Bunker, presentation speaker, indicated his preference for "more knowing dopes and less geniuses".

At the reception that followed were the "knowing dopes" (and a few self-admitted geniuses) who did the pioneer work in rocketry. Solid evidence of this work appeared behind the plastic display windows of the rocket itself, and in cabinets devoted to astronautical telemetering and instrumentation. All control engineers should make an effort to visit this sizable display of previously classified applications of their art.

. . . peer at Viking's declassified innards.

This new simplified digital gaging system remotely measures liquid levels in any number of tanks over a single wire pair of any length.

As illustrated, levels from the dialed tank are read from float-type gages and transmitted in precise digital form to the tank gage receiver. Tank number and level readings, in feet, inches and eighths, are displayed on easy-to-read lamp registers. Continuous monitoring or read-and-hold can be selected as desired. Optional features include automatic sequencing of tank selection, printed read-out by electric typewriter and operation of card-punch apparatus.

For further information on Bendix-Pacific Tank Gaging Systems: Contact Bendix-Pacific, Department 831, North Hollywood, California or our authorized representatives, Instruments, Inc., P.O. Box 556, Tulsa, Oklahoma.

CUSTOM ENGINEERED DATA TRANSMISSION SYSTEMS

In addition to Tank Gaging Systems Bendix-Pacific offers the complete Electro-Span line of high accuracy digital Data Transmission Systems for all remote measurement and remote control purposes. Our application engineers will gladly propose a system to meet your specific requirements.

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Pacific Division
Bendix Aviation Corporation
NORTH HOLLYWOOD, CALIF.

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Build **SORENSEN REGULATION** into your products with these new

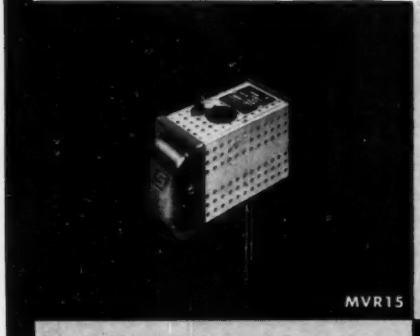
MAGNETIC VOLTAGE REGULATORS

CAPACITIES – 15VA, 30VA, 60VA, 120VA, 250VA, 500VA.

TUBELESS – *trouble free*
COMPACT – *saves space in your equipment*
LIGHTER *than comparable regulators*
GOOD APPEARANCE – *enhances your product*
THERMALLY ISOLATED CASE – *simplifies your design problems*

ELECTRICAL SPECIFICATIONS

Input voltage range	95-130VAC, 1Ø, 60 cycles.
Output range	115VAC, RMS, 1Ø.
Regulation accuracy	±0.5% against line changes.
Load conditions	±0.5% against line at any given load from 0 to full.
Time constant	From 2 to 6 cycles for line changes.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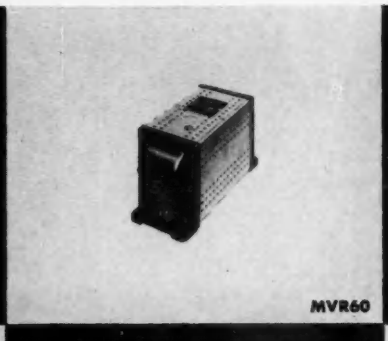
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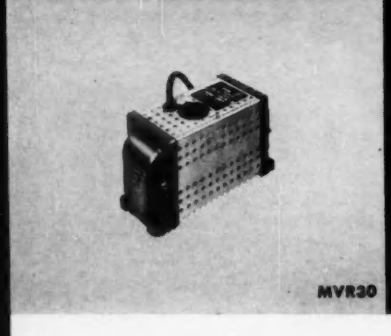
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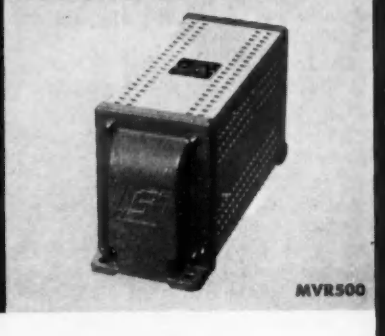
MVR500

GET MORE INFORMATION: Catalog MVR2 is yours for the asking; gives complete data on the new Magnetic Voltage Regulator line. Contact your local Sorensen representative, or write to General Sales Department, Sorensen & Co., Inc., 375 Fairfield Ave., Stamford, Conn.

CONTROLLED POWER FOR **RESEARCH AND INDUSTRY**

SORENSEN

TO AMERICAN BUSINESS...

Thanks for Taming a Wild Horse

This is a message of appreciation to American industry. The occasion for the message is the completion of our eighth annual McGraw-Hill Survey of Business' Plans for New Plants and Equipment.

To a considerable degree, our appreciation is personal. It goes to the companies whose cooperation made our survey possible. Twice as many companies as in any previous McGraw-Hill annual survey carefully answered our questions about their plans to invest in new producing facilities. They gave a great deal of expensive time to the job. The cooperation of these companies, which employ nearly eight million workers, put the results of our survey on the firmest footing, in terms of coverage, it has ever had. For this cooperation we are most grateful.

But our appreciation is much more than personal. It extends in even greater degree to the kind of planning of investment in new plants and equipment which our survey revealed. The nature of this planning holds out promise that American industry is on the way toward bringing under control what historically has been one of the most upsetting forces in the American economy—the violent fluctuations in business capital investment. Progress in ironing out these fluctuations gives occasion for public gratitude.

A full report of the results of the eighth annual McGraw-Hill Survey of Business' Plans for New Plants and Equipment will be sent to anyone requesting it from the Department of Economics, McGraw-Hill Publishing Company, Inc., 330 West 42nd Street, New York 36, N. Y.

Very Good Business News

The part of our surveys that attracts the widest interest is the news they give about immediate business prospects. And this year the news is very good. The survey results indicate that American business as a whole plans to invest $29.5 billion in new plants and equipment this year. That is 5% more than was invested last year, and a new high for any year.

Plans for the years 1956-1958 are also remarkably encouraging in terms of the amount of investment in prospect. American business reports that it is already planning to spend within 3% as much for new plants and equipment in 1956 as in 1955. In the past, the expenditures planned for future years have always been sharply lower than those planned for the current year. This is understandable enough. It is sometimes impossible to anticipate all the expenditures that will be necessary a year or more hence. Thus the fact that plans are already made

to spend almost as much in 1956 as this year is very good news about business prospects. The level of investment now planned for the years 1957 and 1958 is also remarkably high — far higher than ever reported for years that far ahead in previous McGraw-Hill surveys.

Taking the Long View

The fact that these plans exist is of immense constructive significance. It clearly indicates that more and more, and now in dramatic degree, American business is taking the long view in making its plans for capital investment. It is developing a program which, if successfully carried out, will go far toward eliminating the habitual, destructive surging and sagging of what is in effect the central power house of our economic system — capital investment by business. Upon the level of this investment depends not only the general state of our prosperity but our progress in raising the American standard of living with new products and new and better industrial processes.

Seven years ago, when we first asked industry to estimate its capital spending beyond the current year, only a small minority of companies could give us any estimates at all. This year, 87% of the cooperating companies—and it was a far larger number of companies—could comply with our request for estimates for the years 1956-1958.

It Pays to Bet on Growth

A number of developments help explain the increase in long-range planning of capital investment. One is the increasing technical complexity of American industry. It often takes longer, in this complicated age, to work out a successful installation of new plants and equipment. Another reason for long-range planning is American business management's increasing conviction that it pays to bet on the demonstrated capacity of the American economy to grow over the long pull. With this goes a corresponding determination not to let short-term business fluctuations upset individual company plans for growth through addition of new plants and equipment. An additional factor, and one of great and increasing importance, is the sense of public responsibility on the part of American business leaders who want to help prevent destructive swings in the levels of new investment.

It cannot be too strongly emphasized that there is still nothing automatic about the carrying out of these long-range plans for business spending. Actual expenditures are still governed in major degree by the general health of our economy. This is fully attested by the fact that the current business recovery has led to a substantial upward revision of the investment plans reported to us last fall when we made a preliminary check of plans for 1955. Either private economic excesses or a reversal of the recent improvements in federal tax policy could gravely upset realization of present plans. Fortunately, neither of these possibilities seems to be an immediate threat.

The very fact, however, that American business management has made these plans and will do its utmost to carry them out is a development of tremendous constructive importance for the American economy. It means that major efforts are being made to tame what historically has been an economic wild horse—the process of capital investment by business. Both for doing it, and for telling us about it in our annual surveys, we extend to American industry our sincere thanks.

This message is one of a series prepared by the McGraw-Hill Department of Economics to help increase public knowledge and understanding of important nationwide developments that are of particular concern to the business and professional community served by our industrial and technical publications.

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Donald C. McGraw

PRESIDENT

McGRAW-HILL PUBLISHING COMPANY, INC.

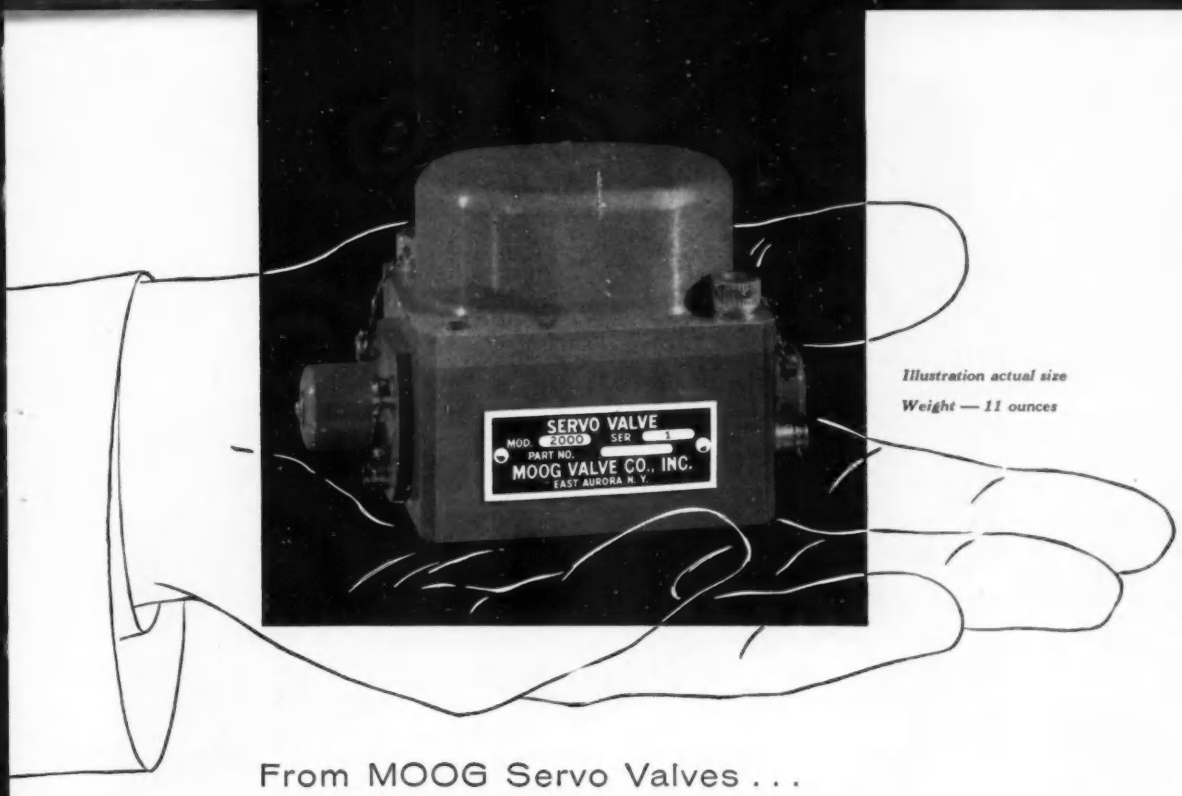


Illustration actual size

Weight — 11 ounces

From MOOG Servo Valves . . .

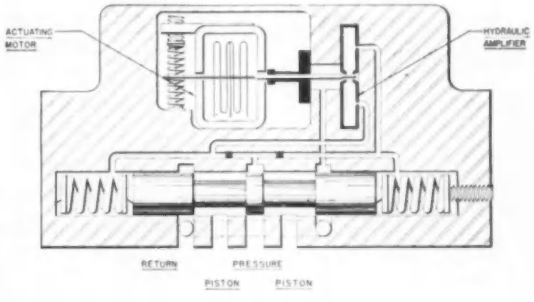
High Accuracy and Response

One of the outstanding characteristics of Moog Servo Valves is their exceptionally high dynamic performance. Moog units are characterized by equivalent time constants as low as one and one half milliseconds from input differential current to output flow.

Performance of this magnitude makes possible control systems of high accuracy and response. Typical applications for these valves are in servo systems of advanced aircraft and guided missile flight controls, radar scanner actuation, contour following machine tools, and automatic packaging equipment.

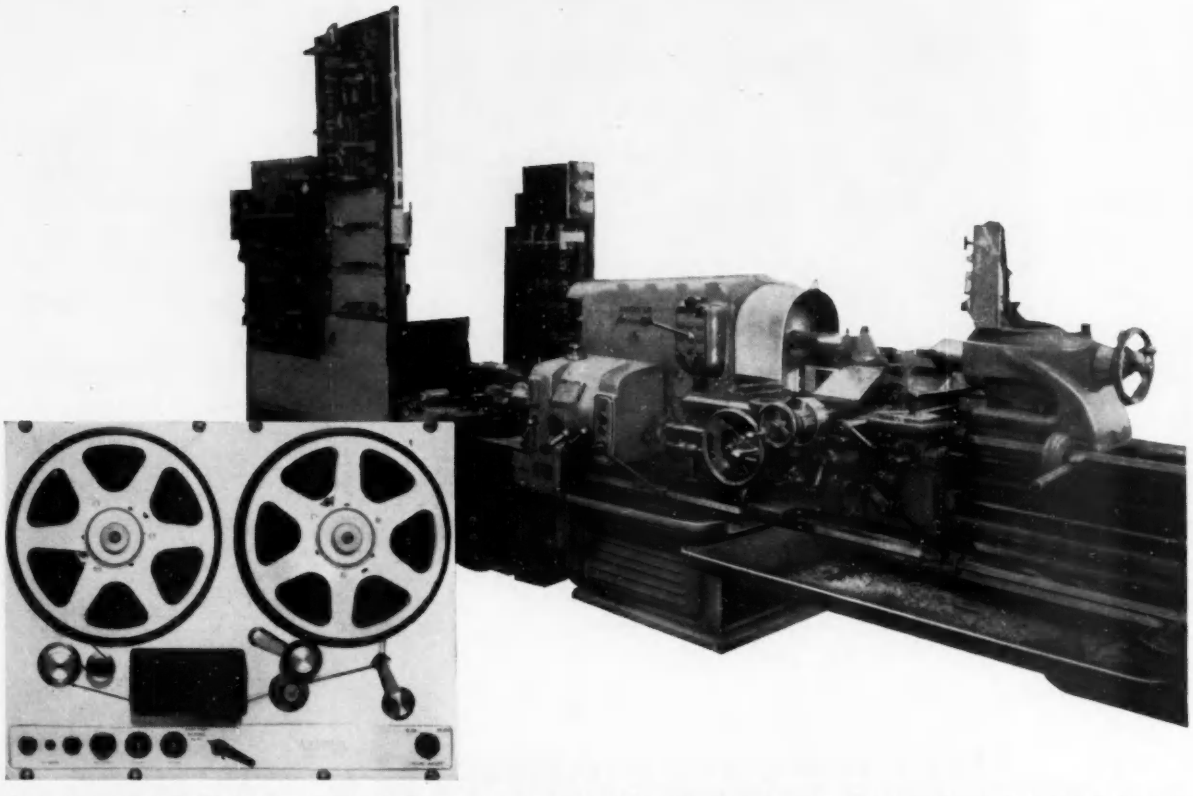
Conventionally, valve input is from a balanced push-pull DC amplifier and valve flow output is applied to a piston or hydraulic motor. An electric signal proportional to piston position or motor angular rotation is fed back to the amplifier to give a closed servo loop.

Production models are designed to operate in hydraulic systems of from 1000 to 3000 PSI pressure. Rated output flow from 0.1 to 50.0 GPM, for control currents between 2.0 and 40.0 milliamperes as specified, are available in production units.



For details write for Bulletin 2000-2

MOOG VALVE CO., INC. PRONER AIRPORT EAST AURORA, N. Y.



MAGNETIC TAPE CONTROLS MACHINES LIKE THIS

An Ampex Magnetic Tape Recorder programmed all operations of this 16" lathe. The Ampex machine was selected by General Electric, who designed and built the control system, to provide the "memory" which helped guide the machine flawlessly through the accurate motions involved in machining irregular parts. For each part to be manufactured, a skilled machinist made the first unit. The Ampex recorder "remembered" his motions and could thereafter direct the lathe in the manufacture of one part or a thousand — now or twenty years from now.

Other exacting work programs of drilling, jig boring, tapping, or gear cutting can be converted into electrical signals by existing tracer techniques . . . and permanently recorded on magnetic tape. The control system using the memory characteristics of this tape can give you an exact duplication of the original work sequence, again and again . . . wherever and whenever you want it. **Result:** machine tool setup time is shortened . . . print reading and "miking" times are reduced . . . operator errors and rejects are eliminated . . . and simultaneous operation of two or more feeds, on two or more machines is possible.

For Your Automation Needs: **Ampex Precision and Durability**

Ampex recorders retain precision even after thousands of hours of use. And they can be adapted to almost any automation need. Let our application engineers determine whether magnetic tape can provide a more efficient control system for your operation — or write for our 16-page bulletin on "Data Recording, Machine Control and Process Regulation."

AMPEX CORPORATION

Signature of Perfection in Magnetic Recorders

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Nuclear Energy Breeds New Markets for Control

Ten years ago the blindfold fell from the eyes of the small group of process control makers who were shipping huge orders to obscure hamlets in Tennessee and Washington state. The control men were dazzled by the promise of what they saw—but not quite sure how to approach it.

Today the dazzle is still there. But now there is no hesitancy in the approach. Instrumentation and control has jelled into one of the most profitable phases of nuclear energy. The control makers have taken stock, dug in, and are proliferating.

Fuel processing a rich pasture

As nuclear technology became clear, three paths unfurled for control products: 1) processing the fuel; 2) controlling the reactors; 3) measuring and controlling with radioisotopes.

As for nuclear fuel processing, it proved to be simply a new pasture for standard industrial type control. True, the pasture is rich: a gaseous diffusion process takes carloads of flow, pressure, temperature, and analytical controllers. But the number of such plants is limited. And the old line industrial control firms—those that shipped to Oak Ridge and Hanford—have grown into this business like endowed and talented sons.

Reactor control is another story. Coping with nuclear furnace dynamics has required new techniques and hardware. And while the process control firms have also stoutly staked their claim, other formidable engineering ensembles, such as American Machine & Foundry, General Electric, and Westinghouse, are now deep into manufacture of control systems for reactors.

From the standpoint of control hardware, reactors are already big business. Take the MTR installation at Arco, Idaho. Controls for this sizable test reactor ran to $340,000—eleven per cent of its total cost. And it is expected that instrumentation for the Duquesne power reactor will be just as large.

Small reactors—big business

Even smaller reactors can mean a bounty for the control maker. Oak Ridge's famous "swimming pool" unit, prototype for an expected flood of small research reactors here and overseas, cost only $94,000. But about half was in control instrumentation. And this healthy ratio may become the rule as small commercial power reactors become available to run transport and industrial plants. When this happens the basic reactor panel must be augmented with automatic controls for the

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process with which the nuclear power supply is "packaged."

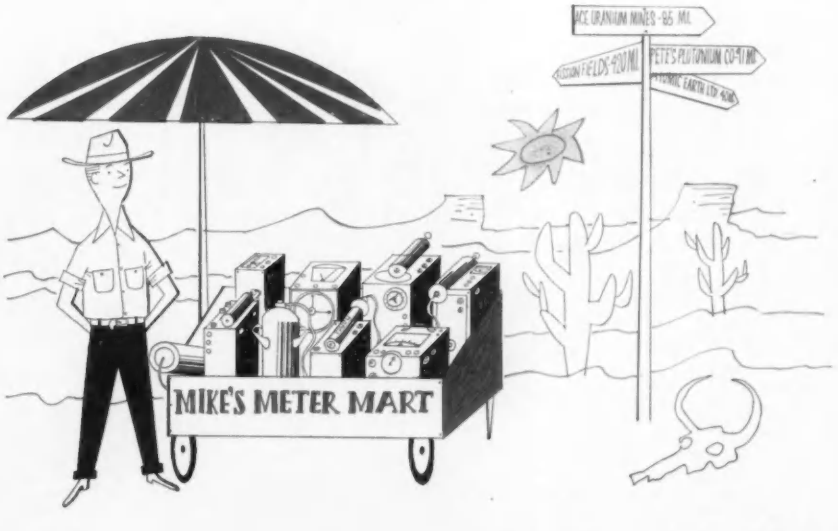
While the big promise of power reactor control still stands five or ten years off, byproduct from the very first nuclear piles —the radioactive isotope—has already fostered a virile new branch of control. Some of the proven industrial uses for radiation measuring techniques: strip thickness control in rolling mills, closed system liquid level control, fluid control in pipelines, gaging of metals in machining, and monitoring closed systems for leaks, wear, penetration, distribution.

The mushrooming of companies that seek to exploit nuclear measurement has been phenomenal. In 1943 there were only three small concerns manufacturing radiation-type instruments. Today over 96 are in the act, churning out an array valued at over $30 million annually. And according to AEC forecasts, the volume is apt to double by 1960.

A close-up of one of the members of this vigorous new crop of control makers confirms the optimism. Industrial Nucleonics Corp. sprouted in Columbus, Ohio, in 1950 with a functional beta gage to measure calender thickness in rubber and plastic. In a few months the "AccuRay" system included automatic control and was serving almost all major tire producers. Next came a scanner for wide paper machines, and then a computer to calculate average weight across the sheet. Eight of the ten largest paper plants quickly bought the system. And in late 1953 "AccuRay" was rigged up to control a tandem steel mill—a system that's almost a standard in the industry.

From beta gage to mill control

What's next for control makers in the radioisotope field? Industrial Nucleonics, for one, sees "more and more over-all system responsibility in control of heavy industrial processes, incorporating monitors, computers, and data handling devices." Judging by work already done, it would seem that this lively young company—and the new branch of control technology it represents—is wasting little time in realizing its future.



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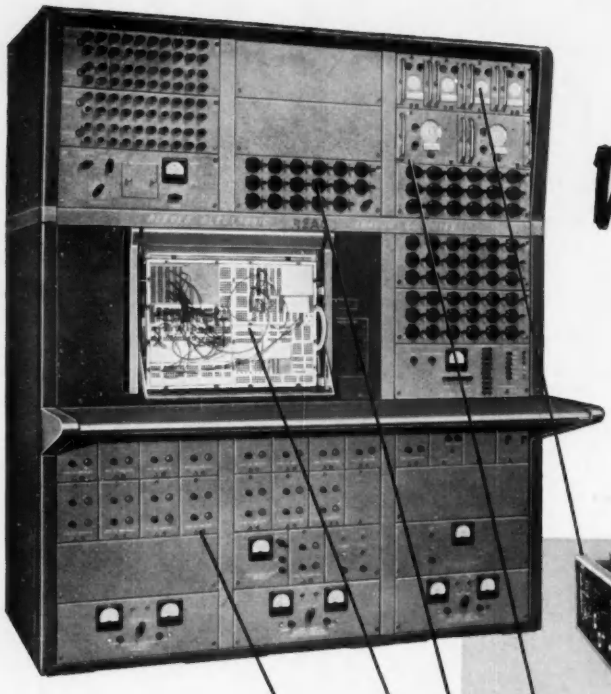

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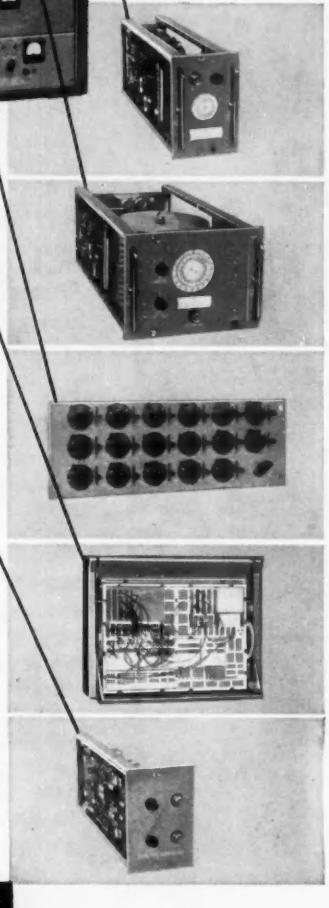

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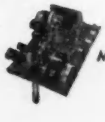

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Your Place in Nuclear Control

The United Nations' international scientific conference held this month in Geneva, Switzerland, to "explore means of developing the peaceful uses of atomic energy" waters the seed of international cooperation. Unesco may, with this start, become the Johnny Appleseed of world peace. As trust grows and security relaxes, the control engineering opportunities in industrial and scientific uses of atomic energy may expand beyond those in girding Mars with more fearful weapons. These opportunities center around the same activities as do the markets for control equipment discussed in this month's *Industry's Pulse*: nuclear fuel processing, control of nuclear power reactors and their associated processes, automatic gaging and inspection with radioactive materials.

Experts disagree on the rate at which nuclear power plants will take up the burden of man's energy demands. But one thing is certain. Because energy liberation by nuclear reaction is more expensive than by burning coal and oil, the thermal efficiencies of the reactors and their turbines must be optimized. Only exacting automatic control systems can accomplish this. And the integration of the generating plants with power distribution systems will require centralized automatic dispatching, data processing — a continually growing volume of control system engineering.

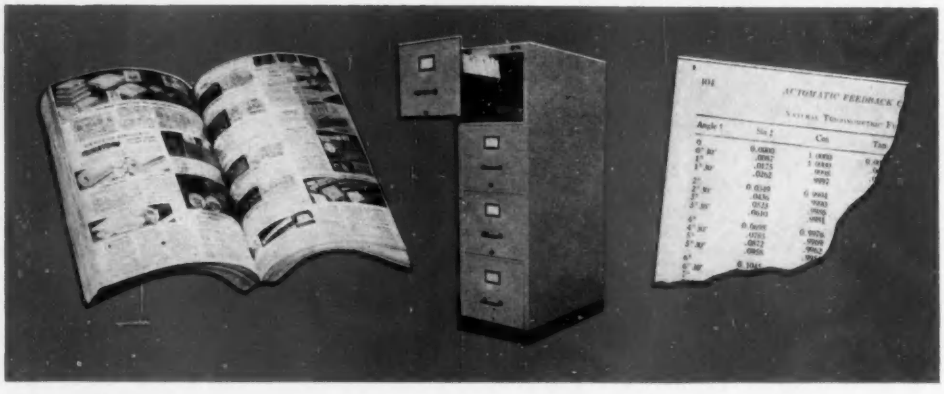
The offspring of the nuclear reactor, radioactive gaging and inspection, though far smaller in unit size, has outstripped its parent in rate of growth. The number of people employed in manufacturing these instruments almost doubles every year. Here is real opportunity for the control engineer bent on development, marketing, or application.

Broadly diversified opportunities are also opening in the production-processing industries where qualified engineers are avidly sought to apply the atomic measuring elements. A recent investment digest lists a broad front of nuclear-activated companies: air frame manufacturers; electrical equipment colossi; chemical, mining, and petroleum processors; metal fabricators; and machinery builders. So before striking out for opportunities elsewhere, check your own company's plans for nuclear control.

THE EDITORS

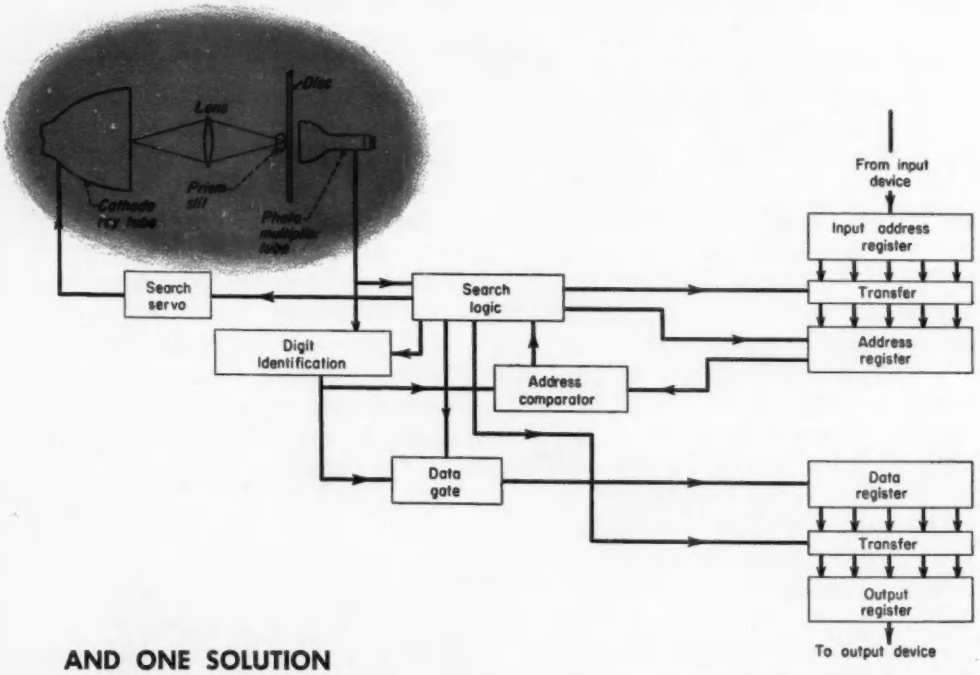
A NEW APPROACH TO

INFORMATION



THE PROBLEM

. . . To store large quantities of information commonly of the order of a billion bits. For example, a table of trigonometric functions for a gun director requires 10^5 bits, the New York telephone directory 10^8 bits, a mail-order catalog 10^9 bits, and the Library of Congress 10^{14} bits. This information must be available for fast and frequent reference for computing and billing and must be adaptable to change or discard. FIG. 1



AND ONE SOLUTION

. . . A photoscopic information storage unit that records coded information using the exposure or nonexposure of areas on a photographic emulsion. High resolution emulsions permit information to be stored at a density of a million bits per square millimeter. Thus a 3 by 5 in. plate of this density would have the capacity of the human mind and a cubic foot could more than handle the Library of Congress. FIG. 2

STORAGE

COMPARISON OF INFORMATION STORAGE DEVICES

	Capacity	Access	Cost per bit	Size of Equipment
MAGNETIC CORES	Relatively low	Very good	Very high	Large
MAGNETIC DRUMS	Low	Good	High	Small
MAGNETIC TAPES	Very high	Poor	Low	Small
PUNCHED PAPER TAPE	Very high	Poor	Low	Small
PUNCHED CARDS	Very high	Poor	Low	Large
PHOTOGRAPHIC	Very high	Good	Very low	Small

GILBERT W. KING, International Telemeter Corp.

The control of many contemporary operations in computing, logistics, libraries, and commerce involves storing large quantities of information. These can be held in an automatic memory on punched cards, or on rolls of punched-paper or magnetic tape. But, paralleling the demand for large stores is one for access time of less than a second. Mechanical form of punched cards and required rolling and unrolling of tape limit capacity and accessibility.

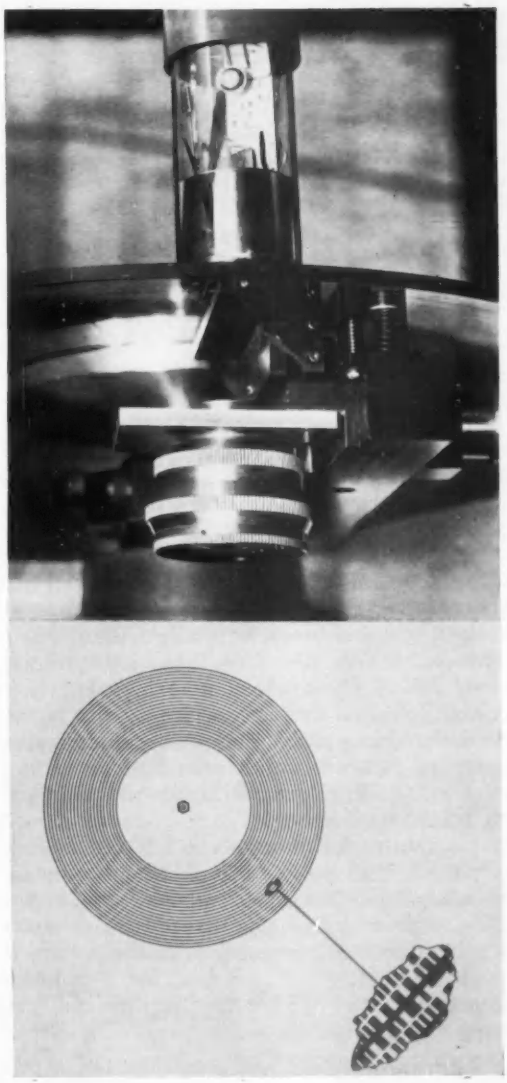
In contrast, photographic techniques offer interesting possibilities because of the storage density capabilities of the new high-resolution silver-halide emulsions and the fast access to the reduced physical storage area. The table above compares characteristics of six information storage devices.

The photographic emulsion is two-dimensional, requiring an area search, and is read with a light beam. There are two ways of finding a given bit of information: movement of the emulsion past a stationary spot of light, or scanning the emulsion with a moving spot of light. A combination of the two gives the lowest access time.

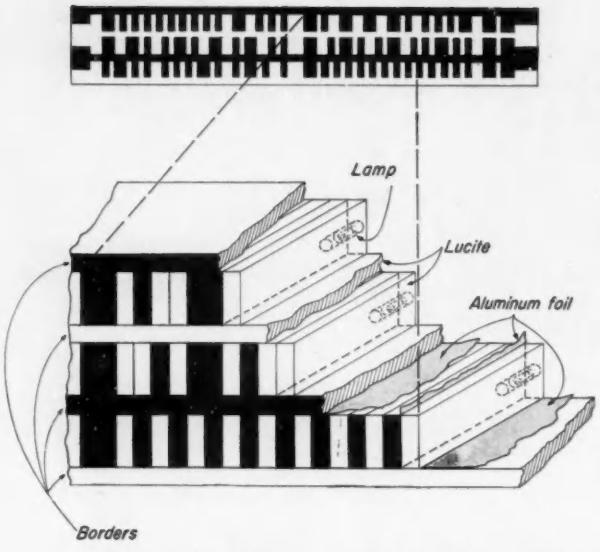
Photographic recordings are hard to erase. But the information in the storage problems considered here is relatively permanent because of its large volume. Nevertheless, even in the largest stores, changes and additions do occur. These can usually be handled by a combination of photoscopic units, or by adding small temporary erasable storage devices of conventional design.

THE STORAGE DEVICE

In photoscopic stores requiring rapid access, the information is held on a transparent disc coated with a photographic emulsion. It can appear on this disc in a coded form that is wholly or partly digital. The digital store consists of a code of microscopic black and white rectangles arranged in concentric tracks. To read information, the disc is rotated while a light beam shines through the information tracks. A



Typical disc showing tracks on outer annulus and detail of black and white coded emulsion. Photo shows lens, disc, and phototube. FIG. 3



These plastic slabs build up a display. Foil prevents light transmission between slabs while lucite sheets form borders. FIG. 4

phototube picks up the light that gets through the disc and converts the sequence of light and dark to electrical signals. Figure 3 shows a 16 in. disc with storage tracks on the outer four in. annulus. The rectangles are only 0.001 by 0.003 in.

The reading station consists of a cathode-ray tube, a lens that projects an image of the spot on the tube onto the information track, and a photomultiplier tube behind the disc. Deflection of the electron beam in the cathode-ray tube moves the spot radially and illuminates any one of the thousand tracks in the four in. annulus. The low switching inertia permits a two-dimensional search of the annulus area, so there is random access in a revolution.

This size disc can store 20 million bits, equivalent to four million characters or several books. At a speed of 2,400 rpm, information is read at a rate of one million bits per sec. The maximum access time to an item chosen at random is the time of one revolution, or 25 millisec. This can be reduced by using several reading heads.

The output of the phototube is fed to computer-type circuits that convert the signal into conventional characters. These are temporarily stored in a shifting register. The required address or index in another register is compared with what is momentarily being read. If it matches, the subsequent information is sent to an output register and temporarily stored until delivered to the output unit.

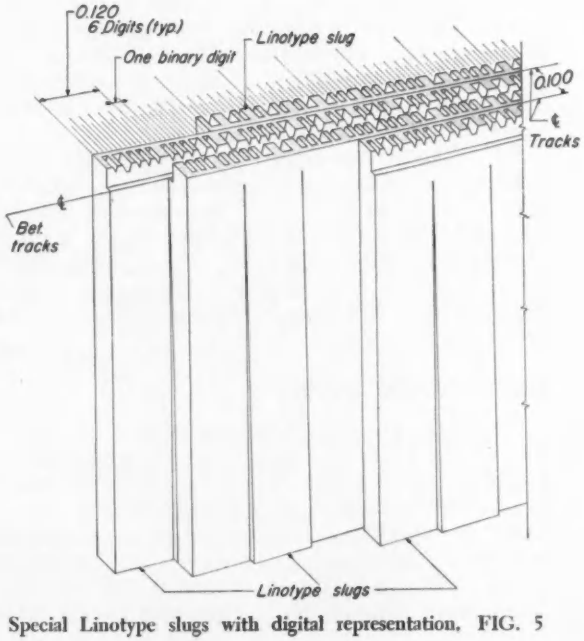
THE RECORDING UNIT

Some applications permit the simplest display of a single light source, and record information bit by bit by flashing a light or opening a shutter and exposing the emulsion on the rotating disc. But the concept of recording 20 megabits serially is not attractive. One reason is that an error or an insertion requires that the whole series be done again. Then too, information is normally supplied at least as characters and usually as words. This suggests that the groups be accumulated in a temporary store, called a display, prior to permanent storage. Proofing then can be done at this stage.

Each display can consist of one or more decks of light boxes, Figure 4. A bulb is inserted in the rear of each plastic slab, and a white or black mark, depending on whether or not the bulb is illuminated, is made on the emulsion. During packing, the slabs are separated by sheets of aluminum foil.

The decks of boxes, corresponding to the several tracks, are separated by dark or illuminated strips that photograph as the guiding borders. Also, punctuation marks that indicate the beginning of new words can be built in. The beginnings and ends of the tracks have "half tracks" that allow each recording to be aligned without registry problems.

The operation of the device depends on the source of information. If the source is a manually operated typewriter, the typewriter's keys actuate appropriate switches so that the proper bulbs light up. If the information is received on punched cards or tape, conventional reading equipment is used, and the electrical signals from the reading heads automatically operate the switches. For example, fully loaded cards can be read at 600 per min. After each word has been set up on the display and photographed, the emulsion is advanced the correct



Special Linotype slugs with digital representation. FIG. 5

amount and new information read in.

Another type of display is a printed sheet pulled from a galley of Linotype slugs. The information is delivered to the Linotype machine a character at a time, either by manual depression of a key or from punched tape. At each stroke a piece of brass on which a raised rectangle is engraved with binary code is brought down to the line being composed. When a line has been composed, a lead casting is made from it. In this application, a line corresponds to a unit record or word of 250 bits, Figure 5.

The galleys are then inked and a proof is pulled on white paper to form the Linotype displays to be photographed, Figure 6. A true proofing operation can be carried out at this step by making a negative of the same size and scanning with a simplified photoscopic device. The sheets pulled from the galleys can also be arranged in a larger display, say a quandrant of a circle. This then can be photographed directly onto the disc.

Note that the slugs are similar to cards and comprise the "unit record" of commercial filing. They can be changed and reordered if desired. Ordinary characters at the beginning or end of the slugs aid in manual arrangement. And the sheets can be rearranged or replaced.

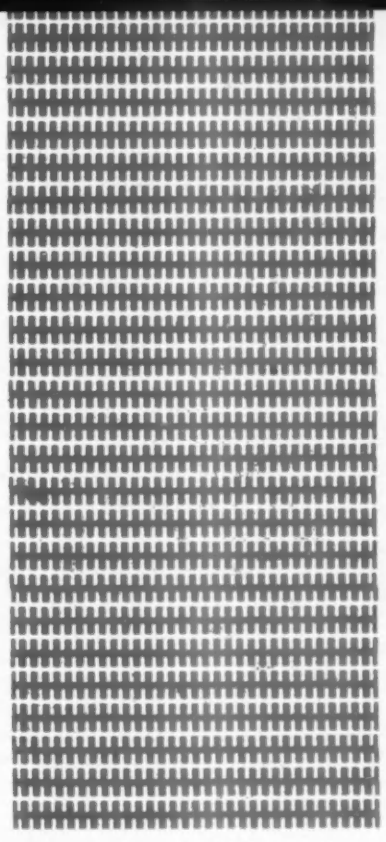
The displays can be photographed directly on the disc, or on an intermediate strippable type film. In the latter procedure, the emulsion can be soaked off the backing and pasted on the disc. The pieces of film attached in this way can be as large as a quadrant of the annulus or as small as a postage stamp. Thus, small accumulations of new material can be added to the disc.

RECORDING PATTERNS

Since the exposure of the film is inherently binary, it is possible to record binary information with black representing zero and white representing one. But this creates the analog problem of determining electronically whether a long black mark is n or n plus or minus one zero digits. To make sure that the detection of digits imposes the minimum requirement on the electronics, a redundant symbol is used for recording binary bits. Two bits of storage are used to record one binary character. With this notation, no message has combinations of digits that result in more than double whites or blacks. Thus, the electronics need only discriminate between singles and doubles, Figure 7.

There is this advantage in the above notation: since the average light intensity over a short string of digits is grey, it is unnecessary to project the spot of light exactly in the track of information. Each track is bordered by a black and white strip, so that wandering from the track changes the dc level from the phototube. These changes actuate a servo to control the deflection of the electron beam.

The borders may be shared to save space, but this means that the sense of the servo is reversed in successive tracks. While complicating the servo loop, this simplifies the circuitry for switching from track to track. If the spot is given a small push in the direction of switching, and the sense of the servo is simultaneously reversed, it automatically settles down in the next track and will not skip a track.



Proof pulled from galley made of Linotype slugs. Character shown is an eight-bit symbol, repeated sixteen times in a row. There are 50 rows, each sharing a black and white border. FIG. 6

It is necessary that no recording be made in certain sections of the track. For example, if the length of track assigned to each word is uniform but the words are of different length, the sections of track not used must be filled with blanks. These blanks can be recorded as "half tracks", Figure 8.

In addition to the basic binary characters, a search routine requires punctuation marks to indicate the beginning of various kinds of information, such as the address and the desired information for output. Since the redundant code used to record binary digits makes it impossible to have odd numbers of singles between doubles of the same type, these arrangements can be used as punctuation marks when combined with the no information symbol.

COMBINED ERASABLE AND PERMANENT STORAGE

Where changes occur frequently, photographing of intermittently received new information is cumbersome. Here it is convenient to have an associated storage device for quickly inserting new information. A magnetic storage element with a capacity of a

small percent of the photoscopic unit usually can accommodate several days' accumulation of new and changed information. When full, its contents are transferred to a photoscopic disc. This can be done independently of the main disc, or the two can read out to produce a new disc.

Using this technique, both the photoscopic and erasable stores must be searched simultaneously. Three conditions arise:

1—Address found only in photostore. Associated information read out.

2—Address found only in erasable store. Associated information read out.

3—Address found in both stores. Information in erasable store is used and the other discarded.

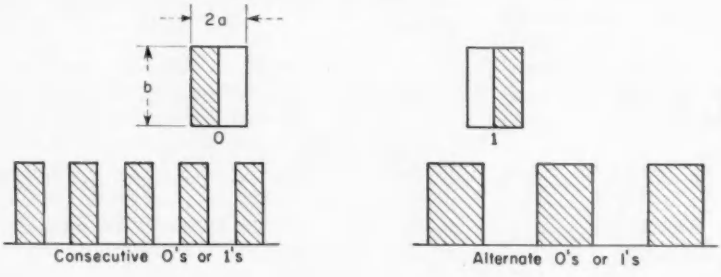
USING THE STORAGE

The simplest scheme is the same as a conventional file. Each item or word has a unique index or address. To find information, the address is set in the machine and the spot scans the disc until this particular address is found. By means of a matching signal the needed information associated with the address is passed to a register and then read out to a printer or visual display.

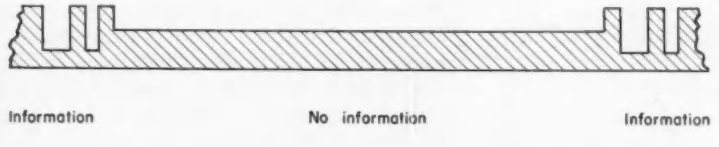
Filling the orders in a mail-order house is typical. Each item in an order must be checked in a catalog for price, size, etc. The number of items in a catalog times the number of bits required per item is about a billion. Over a hundred thousand orders arrive a day, averaging two items per order. Very fast access is required. This relatively permanent information is arranged according to catalog number.

In some files, the information only has value for a specific time. For example, in a credit or liability file, information older than four or five years is ignored. Two expensive operations are made on each entry: in-filing, or putting a new entry in its place in an ordered file, and purging, or removal of the card after the expiration date. The latter requires periodic reading of every card in the file. Access is simple; names are in alphabetical order.

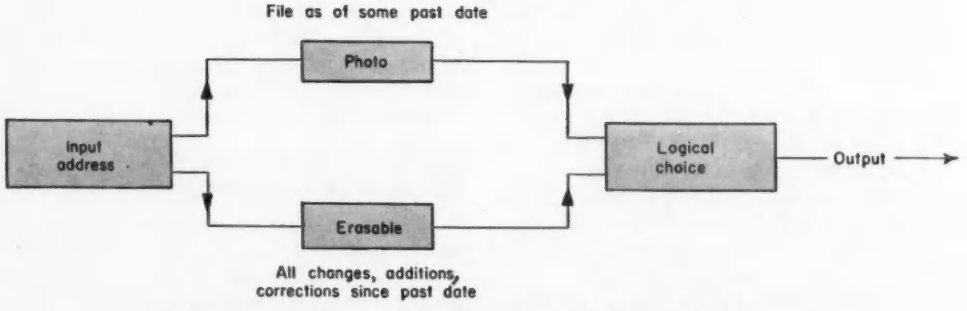
On the other hand, the file can be divided into coarse categories. Assume, for example, that it consists of only the first letters of the name, with a separate drawer for each letter. New cards are sorted only by the first letter and inserted in the front of the corresponding drawer. In-filing is reduced to a minimum and in any drawer the cards are arranged by the date of accession. In purging,



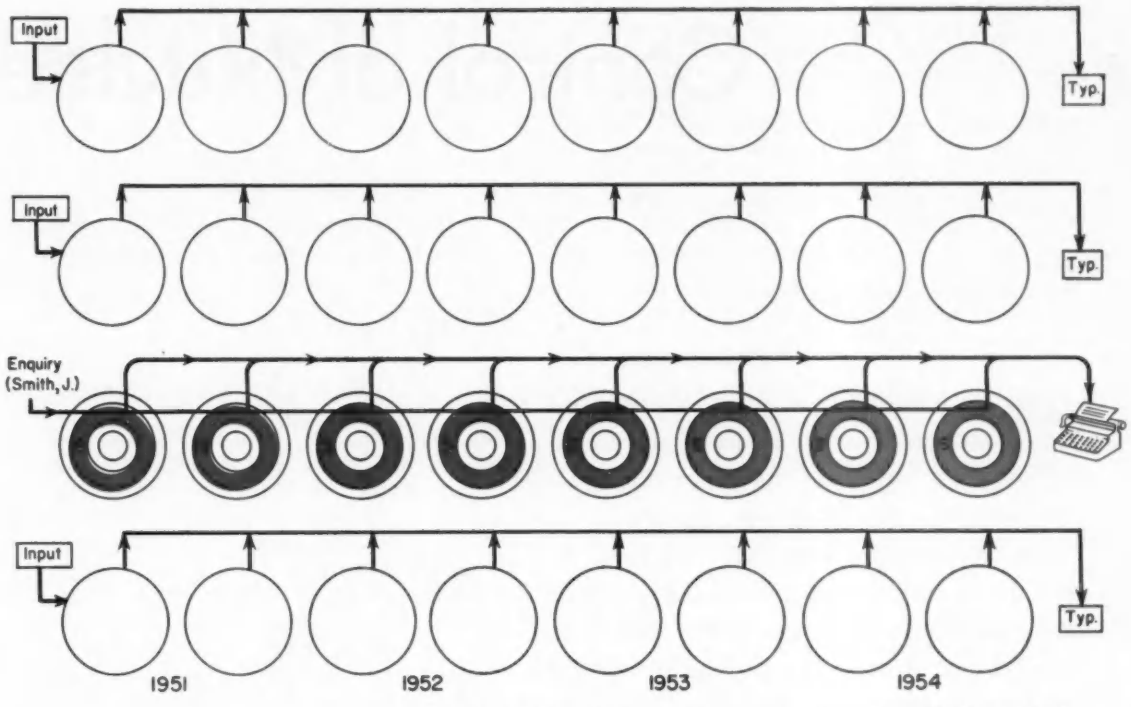
Redundant coding uses two bits of storage to record one binary character. FIG 7



"Half track" symbol records blanks in information. FIG. 8



Combining permanent and erasable storage techniques. FIG. 9



Schematic of photoscopic storage system for four-year credit file. FIG. 10

cards are removed from the rear of the drawer. This is difficult to accomplish manually, since every card must be examined to find an address in a given drawer, but with a photoscopic unit, the high reading rate is exchanged for collation. In a typical commercial file, the information under a particular coarse grouping can be searched in a second or two. If faster access is required, the information can be grouped into more catagories.

Assume that six million names in a typical credit file are held for four years. At this rate of change, four discs must be assigned to each six-month period. Four years' accumulation takes 32 discs. Each disc is divided into eight annuli, so there are 32 areas, each assigned to a letter of the alphabet. To find a particular name the search is carried out simultaneously in the appropriate annulus on each of the eight semi-annual discs, Figure 10. All matching entries are delivered to the output equipment. If necessary, discriminating circuits can reject all but the latest entry.

After a period of four years, the information on four of the discs assigned to the eighth semi-annual period is obsolete, and the discs can be cleaned off and used again.

New information is put on the last bank of four discs. However, the material only has to be sorted by the first letter, and the daily intake for each letter merely has to be put in the appropriate zone. Strippable type film can be used. Precise alignment is not required because of the servo devices built in the reading head.

An inventory machine is a reference file in which each item in inventory is described and a record is kept of the number of items in stock. The list of items, with identification by description, supplier, etc., is relatively permanent. The item count changes frequently, and good control of inventory demands that changes be noted instantaneously. Usually the permanent part of the information is several hundred bits in size, while the item count requires only a few tens of bits. Even in moderate operation, the total volume of information to be stored is several tens or hundreds of millions of bits.

Since about 95 per cent of this information is permanent, this part can be recorded in a photoscopic storage unit while the remaining changeable information is recorded on an erasable medium. When the inventory of an item is to be changed, its description is sent to the permanent storage unit as an address. When the address is located, the photoscopic unit delivers the location in the erasable store where the count of this item can be found. This count is read out of the erasable store, changed by the amount withdrawn or deposited, and the new count is reinserted. No permanent information is recorded in the erasable store. It is only used to store information that can and does change.

Control of Nuclear

J. A. DEVER
Minneapolis-Honeywell Regulator Co.
Brown Instruments Division

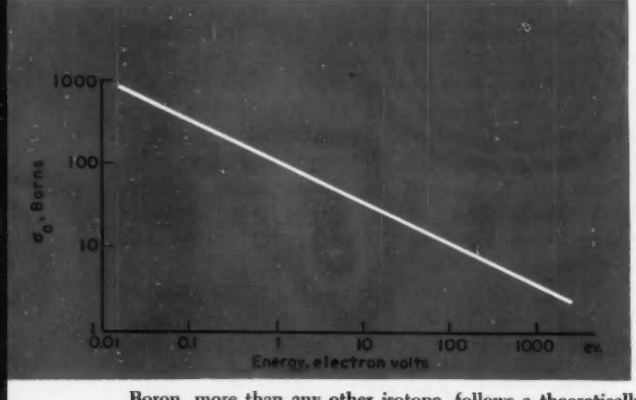
If a nuclear reaction proceeds without the retarding effect of delayed neutrons, the neutron flux, and therefore the reactor power, can increase hundreds of times per second. However, as long as the chain reaction depends, at least in part, on delayed neutrons, the eventual rate of rise drastically slows down and the reactor becomes manageable. Consequently, the control engineer can design a control system with available measuring and control equipment.

The article begins with the fundamental nuclear processes, shows their influence on the time behavior of nuclear reactors, and explains the selection of control means.

The explosive release of nuclear energy is an uncontrolled nuclear reaction. Both explosive and controlled nuclear reactions depend on the fission chain reaction of uranium or other heavy elements (excluding the thermonuclear reactions).

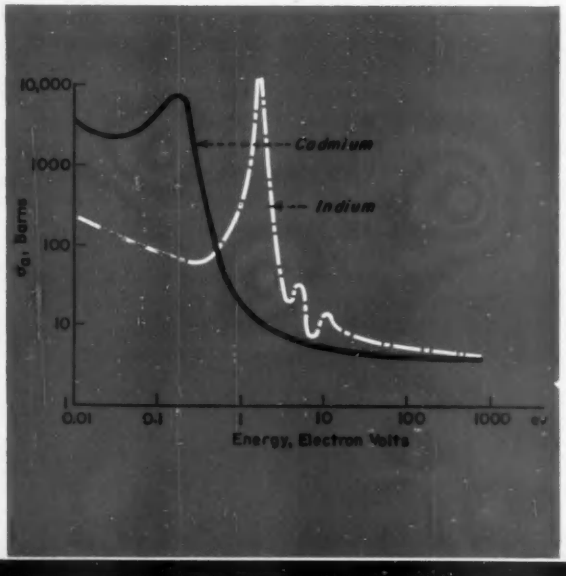
Practically all elements have some tendency to absorb neutrons into their nuclei, the most common result being the formation of radioactive isotopes of the same elements. This is how the many useful radioactive isotopes, such as Iodine-131 and Cobalt-60, are created. Carbon is important as a moderator because it is a solid material of low absorption cross-section, $\sigma_a = 0.0045$ barns. Boron, on the other hand, is stongly absorbent.

More than 80 per cent of U-235's absorption at thermal energies leads to fission, a catastrophic result of adding energy to certain of the heaviest nuclei. A condition of instability threatens in the heavy nuclei, and the capture of a neutron may precipitate fission. Three nuclei, U-233, U-235, and Pu-239, react to neutrons this way, whether or not the neutrons carry any kinetic energy. The reaction releases a tremendous amount of energy—200 million electron volts, or 3.2×10^{-11} watt-sec. Compare this with the 2 to 3 electron volts released from most chemical reactions. While escaping particles and the long-term decay energy of radioactive fission fragments and products carries away some energy, by far the largest part of the energy released by nuclear reaction is kinetic energy, which immediately dissipates as heat in the surrounding materials.



Boron, more than any other isotope, follows a theoretically ideal relationship of absorption inversely proportional to the square root of neutron kinetic energy. FIG. 1 a

The way in which the resonances of Cadmium and Indium complement each other at low energies is why they are widely used in measuring the energy distribution of a swarm of neutrons. FIG. 1 b



Reactors

The reactor, then, is a heat source.

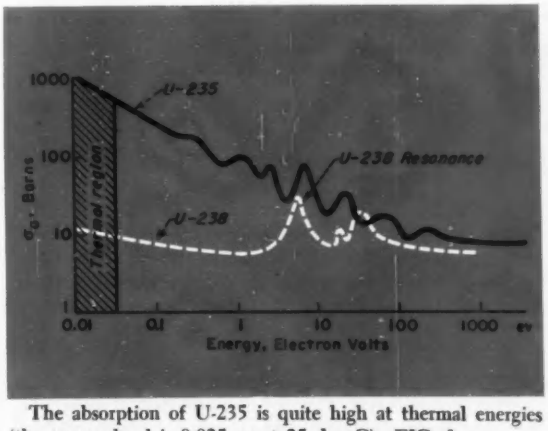
Another nuclear reaction, scattering, is the result of collisions between nuclei and neutrons. Each collision transfers some of the neutron's kinetic energy until it is finally in equilibrium, in the thermal energy range, with the atoms of the moderating material in which it is traveling. The moderating material's scattering cross-section, σ_s, relatively constant with energy, is between 1 and 10 barns.

Chain Reaction

As the capture of a neutron induces the fission process, releasing free or fission neutrons, it is important to so restrict losses of fission neutrons that at least one is available to cause another fission. Absorption that does not lead to fission must be minimized for "neutron economy".

Figure 1c demonstrates the distinct disadvantage of propagating a chain reaction anywhere but in the thermal region, where the large fission cross-section of U-235 can outweigh the U-238 absorption. Gross U-238 absorption is very large because, in natural uranium, U-238 is 140 times more abundant than U-235. Having to use the thermal cross-section is unfortunate, for fission neutrons are very fast, carrying an average of 2 mev. The moderation process decelerates the fast neutrons, getting the neutrons past the U-238 resonance region and into the U-235 fission region.

Figure 2 depicts an idealized chain reaction cycle: fission—fast neutrons—deceleration by the moder-



The absorption of U-235 is quite high at thermal energies (the energy level is 0.025 ev at 25 deg C). FIG. 1 c

TERMINOLOGY TABLE

σ_a = Nuclear cross-section for absorption, measured in units of 10^{-24} cm², or one barn

σ_f = Fission portion of the nuclear absorption cross-section

σ_s = Scattering cross-section

Σ = $N\sigma$, "macroscopic" cross-section, a measure of total absorption for a sample of material containing N atoms/cc

ev = Electron volt

mev = Million electron volts

k_∞ = The multiplication factor of an array of fuel and moderator infinite in all directions. It is defined as the ratio of the number of neutrons at the end of a reaction cycle to the number at its start

k_{eff} = The effective multiplication factor of a *finite* array of fuel and moderator

V = Volume, cc

B^2 = "Buckling", a constant determined by the size and shape of the reactor. For a simple sphere of radius R, $B^2 = \pi^2/R^2$

D = Diffusion constant, a property of the core medium

τ = Age, related to the neutron's deceleration time, sec

L = Diffusion length, proportional to the straight-line distance traveled by a neutron while at thermal energy

t = Time, sec

ϕ = Neutron flux

n = thermal neutron density

$e^{-B^2\tau}$ = fast non-leakage probability

p = resonance escape probability

β = fraction of delayed neutrons

l^* = mean lifetime of thermal neutrons in a *finite* medium

λ = average decay constant of the six radioactive decay processes

C = average concentration of the six radioactive decay processes

T = period, that time required for the power to change by a factor of e = 2.718, sec

$E_1 = n_o - n(t)$ = control system error

E_2 = manipulated variable of control system

N = atoms per square cm

δk, δk_D, δk_E, l, Δ, and d are defined in the body of the article

In a forthcoming article an associate of the author will cover, in detail, instrumentation for reactor counting rate, period, and control. He will also assess instrumentation for the reactor coolant's temperature, flow, liquid level, and pressure.

ating material (carbon or deuterium)—diffusion at thermal energy—fission.

Minimizing the reactor's surface-to-volume ratio maximizes the non-leakage probability, first by arranging the fuel and moderator compactly, and second by increasing size until the effective neutron multiplication factor, k_{eff}, is critical. Surrounding the core with a good scattering material, known as the reflector, reduces the leakage by scattering some of the neutrons back into the reactor. Figure 3 shows the disposition of groups of neutrons during one cycle of a chain reaction in a finite array.

If natural uranium is mixed homogeneously with the moderator, no reaction occurs, regardless of reactor's size. Because of this, the fuel is arranged as in a "heterogeneous" graphite reactor, with slugs of metal placed in a graphite lattice. Then the fast neutrons can leave the vicinity of the uranium and decelerate through the moderator, avoiding resonance absorption by the U-238.

Another solution is the removal of the U-238 isotope. The gaseous diffusion plants were established for this purpose. With the resonance and thermal absorption of the U-238 gone, the fission cross-section of the U-235 predominates and the stringencies of neutron economy relax. Homogeneous reactors are then feasible. References 2 and 3 list all types of individual reactors.

While power describes the reaction rate of the entire reactor, the flux, Φ, of neutrons is the more basic design quantity. Nuclear fission reaction rate per unit volume is

$$\phi\Sigma_f, \text{ fissions per cubic cm per sec}$$

where Σ_f, the fission macroscopic cross-section, equals N, the number of atoms per cubic cm, *times* σ_f. And, as the power generated per fission is 3.2×10^{-11} watt-sec, the reactor-generated power is $3.2 \times 10^{-11} \Phi\Sigma_f V$ watts.

Because the reaction cycle shown in Figure 3 is closed, a gain-loss equation written at any point in the cycle shows the transient variation in the number of free neutrons. The rate of change of n, the thermal neutron density, is,

$$\frac{dn}{dt} = (Production) - (Leakage) - (Absorption) \quad (1)$$

where absorption rate $= \Sigma_a\Phi$ and
leakage $= DB^2\Phi$ (see Terminology Table).

As fast neutrons are the offspring of absorption-induced fission, production is proportional to $\Sigma_a\Phi$, corrected by the cycle's multiplication factor, $k\infty$ and by the fast non-leakage probability, $e^{-B^2\tau}$. Then thermal neutron production, uncorrected for the effect of delayed neutrons, is

$$\Sigma_a\phi k\infty e^{-B^2\tau}$$

Substituting in Equation 1,

$$\frac{dn}{dt} = \frac{1}{v}\frac{d\phi}{dt} = \Sigma_a\phi k\infty e^{-B^2\tau} - DB^2\phi - \Sigma_a\phi$$

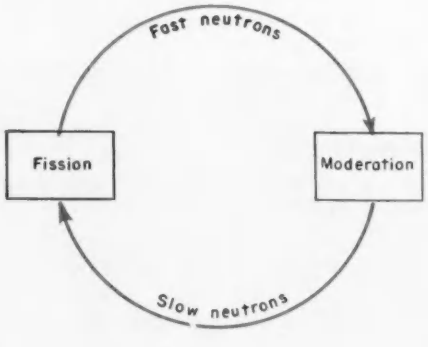
Dividing by $\Sigma_a\Phi$, substituting l for $\frac{1}{\Sigma_a v}$ and using the relation L^2 equals $\frac{D}{\Sigma_a}$, yields

$$\frac{l}{\phi(t)}\frac{d\phi(t)}{dt} = k\infty e^{-B^2\tau} - L^2B^2 - 1.$$

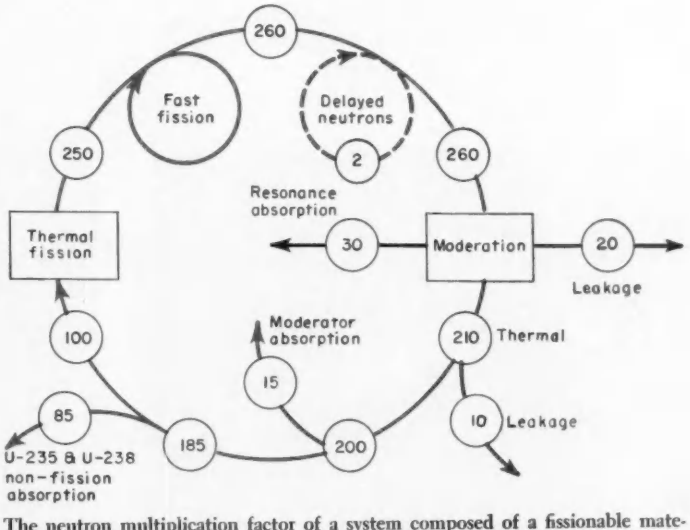
Dividing by $(1 + L^2B^2)$,

$$\frac{l}{1+L^2B^2}\cdot\frac{1}{\phi(t)}\frac{d\phi(t)}{dt} = \frac{k\infty e^{-B^2\tau}}{1+L^2B^2} - 1$$

The term $\frac{k\infty e^{-B^2\tau}}{1+L^2B^2}$ equals k_{eff}, which is unity when



A chain reaction cycle. If k is equal to or greater than one, the reaction sustains itself. The system is "critical" if k = 1. FIG. 2



The neutron multiplication factor of a system composed of a fissionable material and moderator depends on the extent to which neutrons take part in four processes: escape or leakage, resonance capture in the uranium, parasitic capture in the moderator or structural materials, and fission. FIG. 3

the reactor is just critical. For convenience, let $k_{eff} - 1 = \delta k$. The term $\frac{l}{1 + L^2B^2}$ is the mean lifetime of thermal neutrons in a *finite* medium. Represent it by l^*. Making the substitutions and rearranging,

$$\frac{1}{\phi(t)} \frac{d\phi(t)}{dt} = \frac{\delta k}{l^*}$$

Integrating, $\phi(t) = \phi_o e^{\frac{\delta k}{l^*} t}$ (2)

Equation 2 indicates that flux, and therefore power, changes exponentially whenever δk, the manipulated variable, is not zero. If δk is negative ($k_{eff} < 1$), the power falls at an ever-decreasing rate, but if δk is positive ($k_{eff} > 1$), power rises at an increasing rate until either the reactor destroys itself or some non-linearity limits the power level. The rapidity with which power can change is illustrated if $\delta k = 0.0025$, ¼ per cent over critical, and l^* is 10^{-3} sec. Then in one sec the increase is $e^{2.5}$, or approximately 12.

Delayed Neutrons

At the instant of fission, 99.24 per cent of the fission neutrons are emitted. The fission fragments carry along the remainder and release them a minute or more later. Figure 3 includes the action of the delayed neutrons in the cycle.

If $\beta = 0.76$ *per cent* denotes the fraction of delayed neutrons, the "prompt neutron" production of Equation 1 is

$$[\Sigma_a \phi e^{-B^2\tau}] [1 - \beta]$$

The delays come from six radioactive decay processes. The product of their average decay constant, λ, and their average concentration, C, in emitters per cc, is a source term λC, in fast neutrons per cc per second. Multiplying by $e^{-B^2\tau}$ and the resonance escape probability, p, produces an expression for a source of delayed neutrons $p\lambda Ce^{-B^2\tau}$.

Combining prompt and delayed sources,

$$\text{Source} = [\Sigma_a \phi k_\infty e^{-B^2\tau}] [1 - \beta] + p\lambda Ce^{-B^2\tau}$$

The complete equation in Φ now reads

$$\frac{1}{v} \frac{d\phi}{dt} = [1 -]\beta\Sigma_a \phi k_\infty e^{-B^2\tau} + p\lambda Ce^{-B^2\tau} - \Sigma_a \phi - DB^2\phi \quad (3)$$

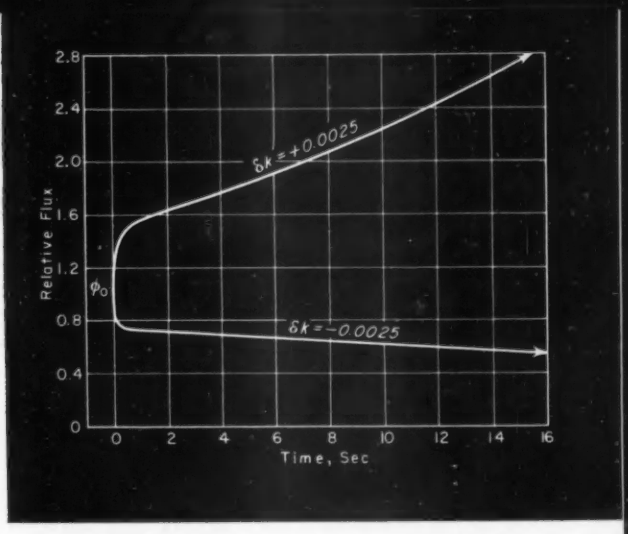
Still needed is a relationship between C and flux, Φ, $\frac{dC}{dt}$ = *production of delayed neutron emitters − loss.*

Loss, through decay, is λC. And as one emitter nucleus takes with it a neutron that would otherwise have been prompt, production of delayed neutron emitters is the same as loss of prompt fast neutrons, $\frac{\Sigma_a \phi k_\infty \beta}{p}$

Therefore

$$\frac{dC}{dt} = \frac{\Sigma_a \phi k_\infty \beta}{p} - \lambda c \quad (4)$$

Application of the appropriate initial conditions produces the approximate simultaneous solution[1, 4]



Flux increases when reactivity, δ_k, is positive and decreases when reactivity is negative. The curves show the flux transients for $\lambda = 0.08$ sec.$^{-1}$, $\beta = 0.0076$, $1^* = 10^{-3}$, and $\delta k = \pm 0.0025$. FIG. 4

when the reactivity, $\frac{\delta k}{k_{eff}} \approx \delta k$, is small,

$$\phi_o \left[\left(\frac{\beta}{\beta - \delta k} \right) e^{\frac{\lambda \delta k}{\beta - \delta k} t} - \left(\frac{\delta k}{\beta - \delta k} \right) e^{-\frac{\beta - \delta k}{l^*} t} \right] \quad (5)$$

Figure 4 shows a plot of Equation 5 for typical values of λ, β, l^*, and for $\delta k = \pm 0.0025$ giving $\phi(t) = \Phi_o (1.5e^{-0.08t} - 0.5e^{-5t})$. Note that while the start of the transient is still fast, the eventual rate of rise is much slower than without delayed neutrons.

The stable "period", that time required for the power to change by a factor of $e = 2.718$, is

$$T = \frac{l^*}{\delta k} = 0.4 \text{ sec, neglecting the delayed neutrons;}$$

$$T = \frac{\beta - \delta k}{\lambda \delta k} = 25 \text{ sec, accounting for them.}$$

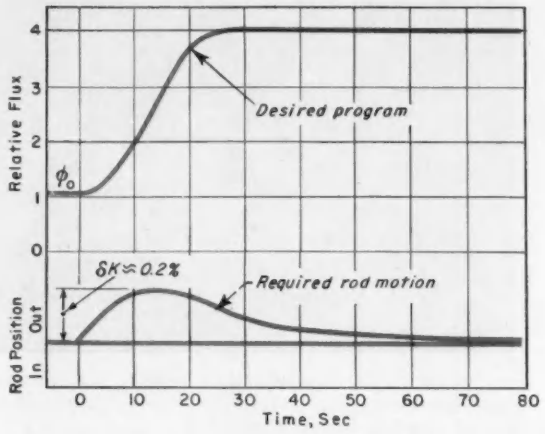
During normal reactor operation, periods of 5 sec or faster are common.

Harnessing Reactivity

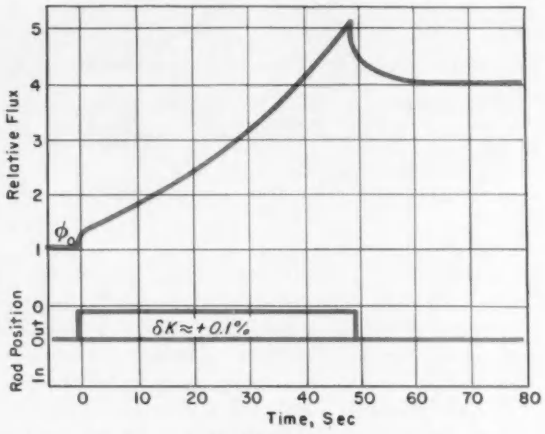
The job of keeping the tremendous range of reactivity in line usually falls to control rods, movable neutron absorbers made of boron or cadmium. They remove neutrons from the cycle of Figure 3 in amount proportional to their proximity to the core. Cable and winch, or rack and pinion, mechanisms drive the rods horizontally or vertically. Electric motor or hydraulic drives with standby power sources provide for safe failure.

The rods number from three to several hundred. They are classed as:

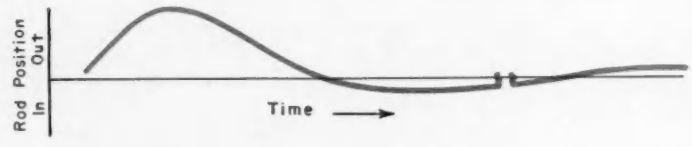
- Safety rods if they control a large amount of k.
- Shim rods if their effectiveness is moderate and they make coarse adjustments in k.
- Regulating rods if they govern small amounts of k by fine manual adjustments or in response to a controller. Reactivity control is not restricted to rods. In some cases rods are secondary to manipulation of fuel concentration or reflector position, techniques that are especially effective where fuel and/or reflector are liquid.



With control rod withdrawal, reactor power rises exponentially at a period inversely related to rod displacement. The power stabilizes, but at a different level when the rod is returned to its initial position. FIG. 5



The slow return of the delayed neutron emitter concentration to equilibrium makes necessary the continuing motion of the control rod, long after the power is at its new value. FIG. 6



Control rod motion for power increase when there is poison present. During a portion of its stroke, the rod is driven inward beyond the initial equilibrium point to offset the increased reactivity due to poison burnup. It finds a new equilibrium position as the power levels off again because the final poison level is greater. FIG. 7

MANUAL CONTROL

Consider that one rod represents all reactivity control devices and that it can make the reactor super- or sub-critical by motion in or out. Due to the variable flux intensity over the reactor volume, peaking at the center and falling to zero at the edges, the change in k is not linear with rod position. Nevertheless, at some intermediate point in the rod's travel, k_{eff} will equal unity and δk will be zero. The power remains constant as long as the rod stays in that position. Figure 5 shows power response to step rod motions.

One can postulate a desirable power program and find, in turn, the required rod motion, as Figure 6 illustrates. For smooth power change the operator must duplicate this pattern of rod movement.

Several other factors affect reactor transient behavior. The two principal ones are temperature effects and poisoning.

Temperature Feedback

As a reactor's power level becomes appreciable, the system temperature increases, affecting the reactivity in two ways:

► The thermal neutron energy rises. As the nuclear cross-sections are functions of energy, the absorption rates change.

► Thermal expansion of the reactor structure decreases the material density and alters the mean free path length and leakage probabilities.

A negative coefficient of temperature expansion is highly desirable for its stabilizing influence on the reactor. In an aqueous homogeneous reactor, for example, expansion of the fluid core moves fuel away from the reacting region, damping power excursions.

Neglecting any closed heat transfer paths, increase in power from one level to another in a reactor with a negative temperature coefficient demands eventual return of the rod, not to its original position, but to a location farther out of the reactor.

Poison

Reactors operating at high flux develop suicidal tendencies. Several of the nuclei formed by fission products are strong neutron absorbers. The time variation of the poison is sufficiently slow to be studied apart. The poison is present in comparatively small quantities when the flux is below 10^{12} neutrons per square cm per sec (approximately peak flux in large graphite reactors). It rises rapidly as the flux increases and approaches a maximum of 5 per cent equivalent reactivity at $\Phi = 10^{15}$ (higher

flux than attained in any controlled reactor).

The excess reactivity to override the large buildup and decay after shutdown can easily be many times the $\frac{3}{4}$ per cent necessary to become prompt critical. If it were not for the slow time scale, instability would threaten, for when δk is positive, the consequent flux increase burns out some of the poison, making the reactivity still higher. Rod motion must then follow the pattern of Figure 7 to provide a smooth increase in power.

The latent pressure of the extra reactivity built into the reactor to overcome adverse temperature, poison, burnup, etc., accentuates the need for high speed instruments and controls.

AUTOMATIC CONTROL

During start-up and frequently for any but minor power level changes, the control rods are operated manually. Once the power level is near its desired value, however, relief from tedious adjustment and accuracy of control make desirable some type of automatic controller.

Differential Equations 3 and 4 are simplified by making the same substitutions that were made to arrive at Equation 2,

$$\frac{dn}{dt} = \left[(1 - \beta) \frac{k_{eff}}{l^*} - \frac{1}{l^*} \right] n + p\lambda C e^{-B^2\tau}$$

$$\frac{dC}{dt} + \lambda C = \frac{\beta k_{eff}}{l^* p e^{-B^2\tau}} n$$

$$k_{eff} \approx 1; \quad \text{therefore,}$$

$$\frac{dn}{dt} = \left[\frac{\delta k}{l^*} - \frac{\beta}{l^*} \right] n + p\lambda C e^{-B^2\tau}.$$

δk is a small time-variable input; then

$$n = n_o + \delta_n \quad \text{and} \quad C = C_o + \delta C.$$

Substituting,

$$\frac{d}{dt}\,\delta n = \frac{\delta k}{l^*} n_o + \frac{\delta k}{l^*}\,\delta n - \frac{\beta}{l^*}\,\delta n + \delta C\, p\lambda e^{-B^2\tau}$$

and

$$\frac{d}{dt}\,\delta n + \lambda \delta C = \frac{\beta}{l^* p e^{-B^2\tau}}\,\delta n.$$

Taking the Laplace transform of both equations, solving the second for δC, and substituting the result in the first, gives

$$s\,\delta n(s) = \frac{\delta k}{l^*} n_o + \frac{\delta k(s)}{l^*}\,\delta n(s) - \frac{\beta}{l^*}\,\delta n(s) + \frac{\lambda\beta}{l^*(s+\lambda)}\,\delta n(s)$$

Dropping the insignificant product, $\delta k\,\delta n$,

$$\left(s + \frac{\beta}{l^*} - \frac{\lambda\beta}{l^*(s+\lambda)} \right) \delta n(s) = \frac{n_o}{l^*}\,\delta k(s)$$

Clearing,

$$\left[\frac{s(s+\lambda)l^* + \beta s}{l^*(s+\lambda)} \right] \delta n(s) = \frac{n_o}{l^*}\,\delta k(s)$$

then

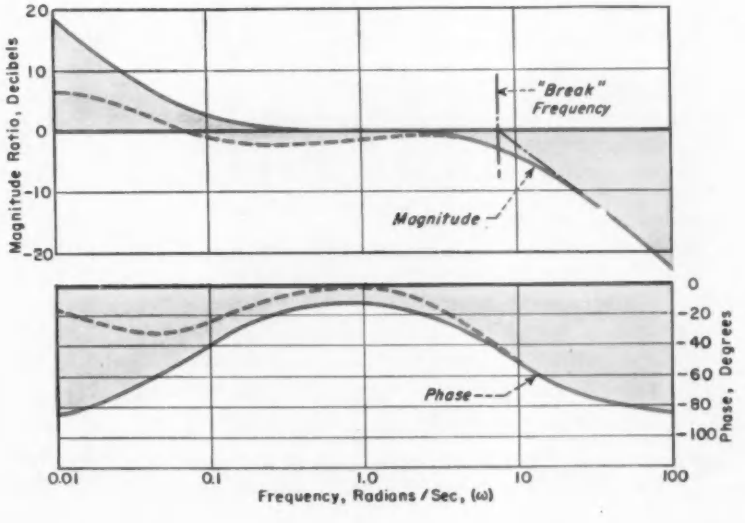
$$\frac{\delta n}{\delta k}(s) = \frac{n_o}{l^*} \frac{(s+\lambda)}{s\left[s + \left(\lambda + \frac{\beta}{l^*} \right) \right]}$$

or

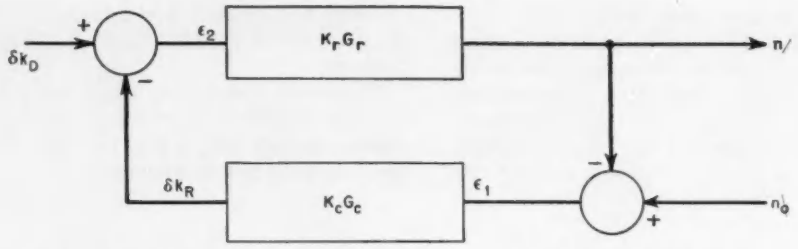
$$\frac{\delta n}{\delta k}(s) = \frac{n_o}{s\left[l^* + \frac{\beta}{s+\lambda} \right]} = K_r G_r \qquad (6)$$

The frequency response of $K_r\,G_r$ calculated from average values of the constants, is plotted in Figure 8. The multiplicity of delayed neutron groups will change the curve shapes slightly. Considering all six groups of delayed neutrons, $K_r\,G_r$ is

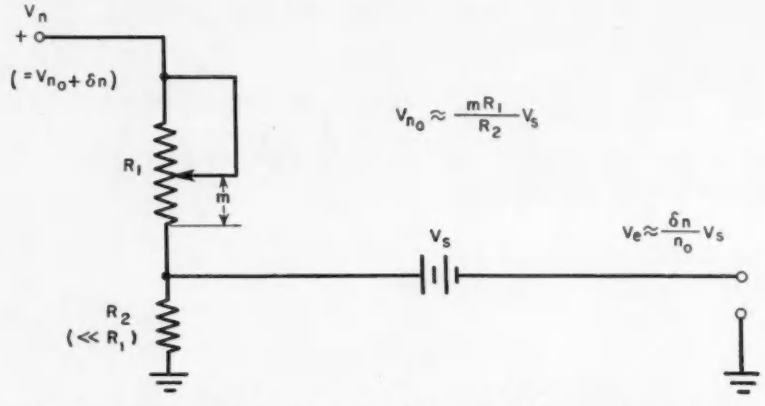
$$K_r G_r = \frac{n_o}{s\left[l^* + \sum_{i=1}^{6} \frac{\beta_i}{s+\lambda_i} \right]}$$



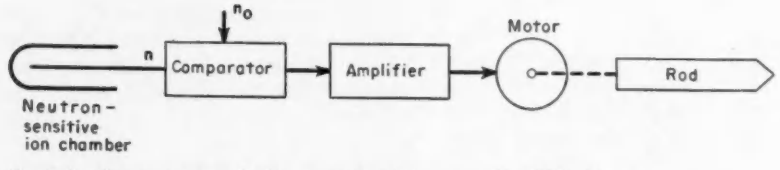
Increasing magnitude ratio and approach of the phase lag to 90 deg reveals that the reactor is an imperfect integrator. Dashed lines show the effect of a negative temperature coefficient. FIG. 8



Reactor control loop. δk_D is a reactivity disturbance, and δk_R is the reactivity due to control rod manipulation by the controller. FIG. 9



The output voltage fed to the error amplifier is inversely proportional to n_o, linearizing the overall performance of the reactor control system. FIG. 10



Control rod moves at a velocity proportional to error, E_1. FIG. 11

The essential features shown by Figure 8 remain.

Consider the control loop shown in Figure 9, where $K_c G_c$ stands for the unspecified controller's transfer function. When n_o, the demand power level, is changed, with $\delta k_D = O$, δk_R develops. The reactor integrates δk_R until $n = n_o$, when the error disappears, as do δk_R and E_2, and the reactor stabilizes at a new level. So far, the controller could be a simple proportioning one.

Next, examine the behavior when n_o is unchanged and a finite disturbance, δk_D, occurs. E_2 develops, n changes, and a correcting δk_R develops in response to error, E_1. However, E_2 cannot vanish unless $\delta k_R = \delta k_D$, implying an error $E_1 = n_o - n_1$. A large proportional gain, K_c, reduces the offset, but does not eliminate it unless G_c includes an integrating action. One concludes that the controller should have floating or resetting action to drive the control rod in a corrective direction at a speed proportional to the difference between n and n_o.

The major distortion in picturing the reactor as an integrator comes from the influence of a negative temperature coefficient. A sub-loop around the reactor, feeding back a retarded signal proportional to n, represents a power-heat, capacity-temperature effect. The frequency response curves shift to the dashed ones shown in Figure 8. Note that the magnitude ratio levels off and the phase lag holds at less than 30 deg at low frequencies. This means that withdrawal of a rod will raise the power to a new level only, not indefinitely.

A second factor of great practical importance is that the neutron power level, n_o, in the equation for $K_r G_r$ is not a constant but is actually the level itself. Therefore, the reactor "gain" increases with power level, posing stability difficulties in the operation of a closed-loop control system. Fortunately, comparator circuits such as that shown

in Figure 10 compensate the non-linearity.

In the control mechanism shown schematically in Figure 11, the control rod reactivity added to or removed from the reactor is the integral of the error, E_1. Hence it introduces a 90-deg phase lag between E_1 and δk_R of Figure 9. Coupling the mechanism to a reactor with perfect integrating characteristics would produce a system that could never be stable. The delayed neutrons, by decreasing the phase lag of the reactor through a frequency range, produce an increased phase margin that allows for stability by adjusting system gain or rod speed.

When control rod servo performance is limited, the reactor's high break frequency concerns the designer. The break frequency, shown in Figure 8, is determined chiefly by β/l * and varies from around one cycle per sec to nearly 100 cps.

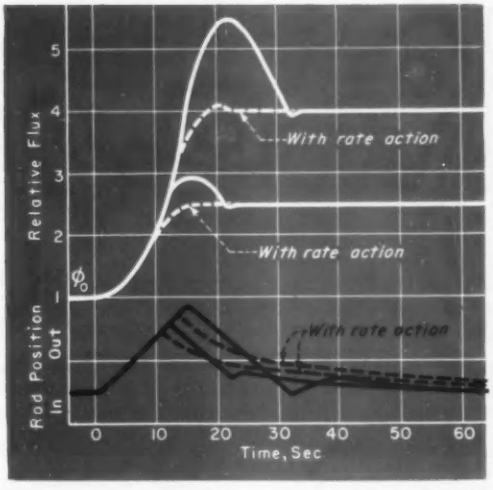
A negative temperature coefficient clearly improves the phase margin of the control system. It is, nonetheless, unwise to rely on the temperature coefficient to resolve an otherwise dubious case because the power level may easily be below 10 per cent while under automatic control. At such a low power level, the temperature may not be sufficiently high to exert an appreciable stabilizing effect.

Frequency response computations must include lags introduced by system components other than the reactor and the rod driving mechanism. The principal subsidiary lags are those of the motor and its transmission, and the rod inertia. The frequency bandwidths of the error amplifier and of the neutron-sensitive ion chamber are normally wide.

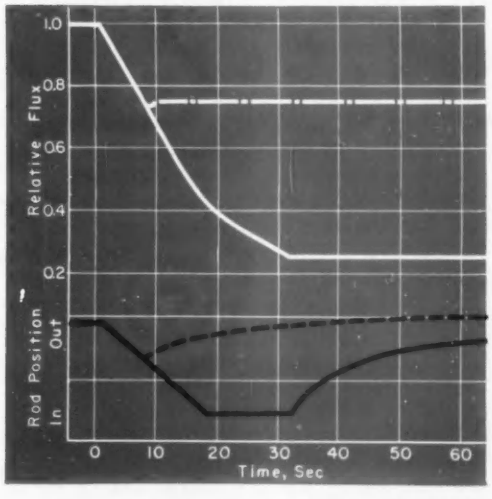
If, after all lags are accounted for, the phase margin is uncomfortably small, a tachometer feedback loop can improve the margin. And "rate", or derivative, action is an effective remedy. Here the first derivative of n is added to the error and the rod speed made proportional to their sum. The obvious benefits of rate action led to its use in the first reactor. Rate sensitivity is simply obtained by a passive phase-lead network. A more elegant approach employs a reactor "period" signal.

When possible, control system components are assembled and tested to determine $K_c G_c$. Or a reactor kinetic simulator [7, 8] may reveal system performance. Figures 12 and 13 show typical responses of $n(t)$ to upscale and downscale changes in n_o demonstrated by a reactor simulator. The figures also show the control rod motions that were necessary to produce the $n(t)$ responses. The controller had a very narrow proportional speed range, saturating at maximum velocity by the time the power deviation reached one per cent.

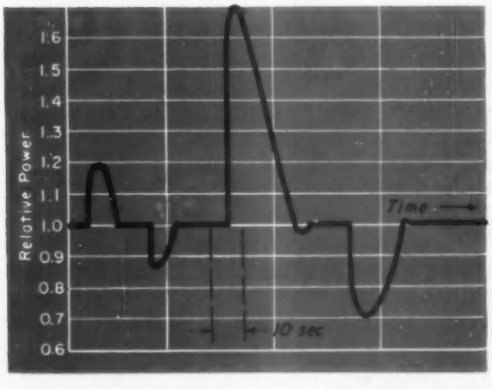
The overshoot produced for upscale changes is a natural consequence of the speed-proportional mode where rate action is not used, inasmuch as rod return to equilibrium cannot begin until after the error sign changes. Increased amplitude of the n_o step causes a longer $n(t)$ excursion below the set point, allowing greater rod withdrawal and



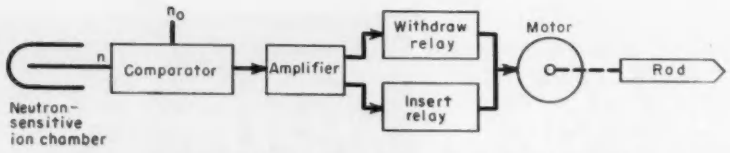
Rate action produces the improvement shown by comparison of the dashed lines (proportional speed plus rate) with solid lines (proportional speed only). FIG. 12



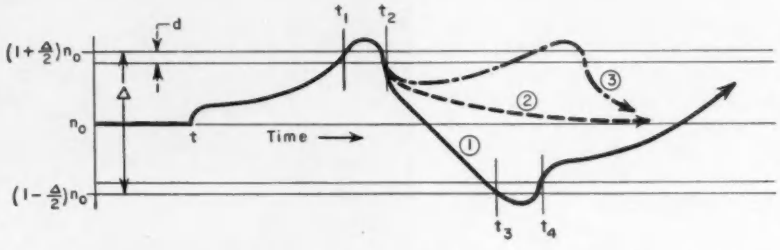
Because the rate of power fall slows as the level decreases, the control rod "bottoms". Power then falls exponentially to n_o, the rod resuming control. FIG. 13



Response of power to sudden disturbances. FIG. 14



If the power exceeds the set level, the contactor servo drives the control rod in the corrective direction until the error is within limits. FIG. 15



At time t_0 the reactor, which has been just critical, reacts to a small positive step in δk, causing η to rise. At time t, corrective action begins with pull-in of a relay. By time t_3, when the relay drops out, a downward transient is established, followed by a slower fall (curve 1), to the lower limit at time t_4. Pull-in of the other relay reverses the trend by withdrawing the control rod until t when η re-enters the dead zone and the cycle repeats. FIG. 16

power acceleration. This leads inexorably to larger overshoots. Rate action effectiveness is most pronounced in suppressing this type of transient.

Small downscale steps are similar to small upscale steps, but Figure 13 shows that reduction of the power level by 50 per cent or more results in considerably different behavior.

Figure 14 shows the power excursions stemming from abrupt disturbances, both positive and negative. Upward surges, such as might follow accidental removal of a neutron absorbing material, can be very serious if the reactor is already operating near full power. To minimize the transients, the control system must be as fast as possible.

One of the simplest control modes, a contactor servo, can control a reactor. Figure 15 shows an arrangement of components: a pair of relays in the output of a simple amplifier is so connected that energizing one causes the control rod drive to operate in one direction at full or saturated speed, and vice versa. The discontinuous control cannot produce the exactness of control that a continuous control does, as the power cycles through the dead zone between the actuation points of the two relays. Figure 16 illustrates the cycling in relation to the dead zone, Δ, and the relay differentials, d.

Ideally, n should follow curve 2 in Figure 15. It is difficult to achieve this condition due to small but continuous δk fluctuations coming from motions of the core, etc. One assisting factor is the initial reactor transient shown in Figure 4. Adjustable parameters are control rod speed, dead zone width, and the ratio d/Δ. Harrer and DeShong[9] have analyzed their effects on stability.

The principal advantages of this type of control are its simplicity and its ease of handling large amounts of motive power through contactors rather than through vacuum or gas tubes. Precision of control is generally within plus or minus 0.5 per cent, more than adequate for most applications, particularly power generating reactors where very close control is not necessary. At the same time, acceptability of discontinuous control opens the door to the employment, without extensive modification, of a number of industrial proportioning relays incorporating automatic reset.

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ANOTHER USE FOR THE SPHERE:

The Tangent Integrator

EDWARD BURGESS, Ford Instrument Co., Division of Sperry Rand Corp.

Unlike the component integrator (CONTROL ENGINEERING, October 1954), which uses the sphere to integrate the components of its input, the tangent integrator generates the same integral as the ordinary disc and wheel. But it has the high torque delivery of the spherical type.

The spherical integrator can transmit somewhat higher torque without slip than the ordinary ball and disc because its contact pressures can be higher. This is due partly to the random way that wear is distributed over the spherical surface. The price that must be paid is a slight loss of precision due to alignment difficulties and unsymmetrical elastic distortions.

The guiding design principle of spherical integrators is that the instantaneous axis of rotation of the sphere must lie in a plane containing the axle of a fixed-center contacting roller and the center of the sphere. The fixed-center specification for the roller implies that the roller may rotate about its axle while the axle itself may rotate about a fixed axis through the center of the sphere and the point of contact of the roller.

For the tangent integrator, however, the axles of the cage rollers may rotate around the sphere center. Thus the directions of two axles of fixed-center rollers (input and steering) in pressure contact with the sphere determine the direction of the instantaneous axis of rotation of the sphere.

The angular velocity of one element only is arbitrary; i.e., when the angular velocity of one roller is specified, the angular velocities of the sphere and the other rollers are determined. Further, the axle of any other fixed-center contacting roller must be coplanar with the instantaneous axis of the sphere and will have a determinate angular velocity.

THE DEVICE

The tangent integrator's output is taken from the component motion of the sphere parallel to the equatorial plane by rollers mounted on a ring output gear. The rollers are free to rotate with the component of sphere motion normal to the equatorial plane at the particular point of contact. Contact pressure is supplied by force on the steering roller axis.

The steering roller angle, A, is set by the linear displacement x acting through the forked crank on the steering roller angle axis.

$$\tan A = \frac{X}{D}$$

From Figure 3:

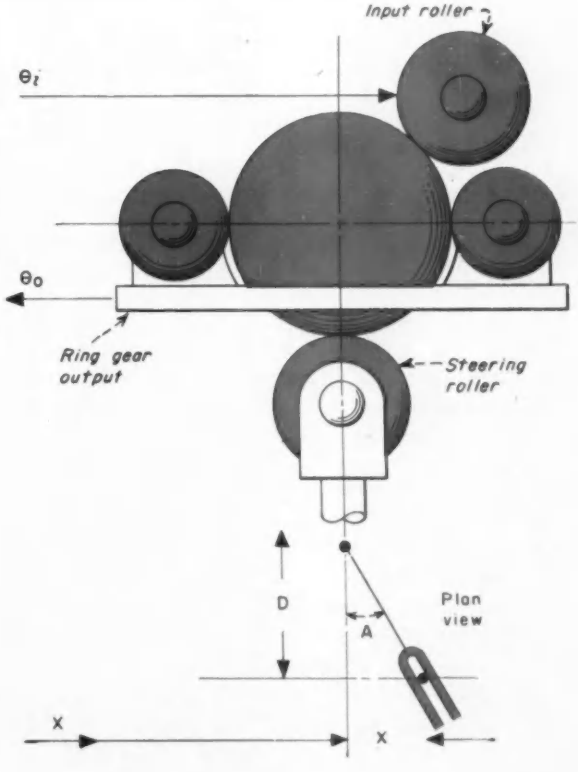
$$\theta_o = \int k \tan A \, d\theta_i$$

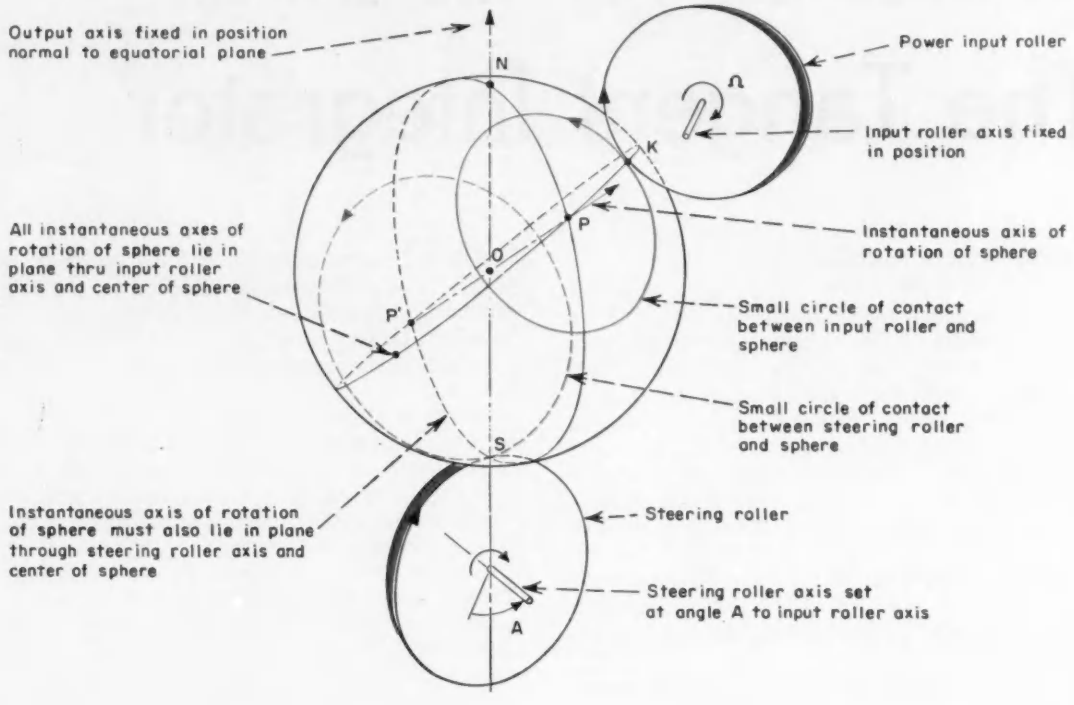
Thus, if

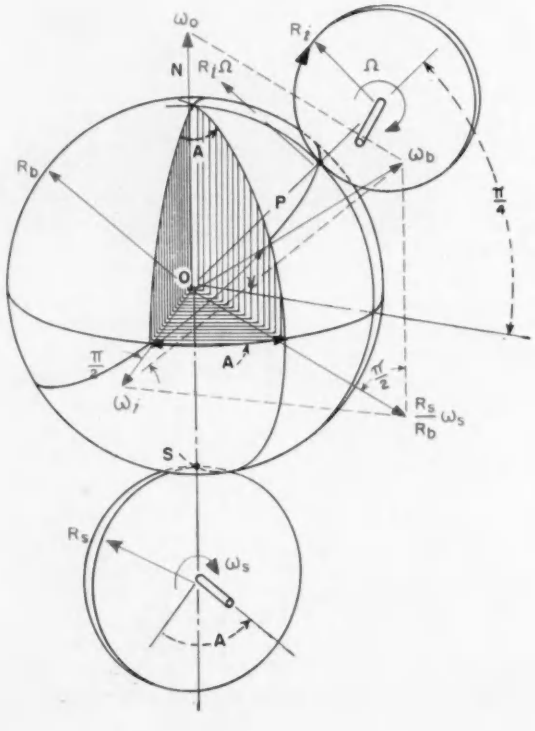
$$\theta_i \propto t, \quad \text{and} \quad \tan A = \frac{x}{D}, \quad \text{then}$$

$$\theta_o = \frac{k}{D} \int x \, dt \text{ and therefore}$$

the tangent integrator is equivalent to an ordinary disc, ball and cylinder integrator. Normal operating limits are A = plus or minus $\pi/4$ radian.




Output axis fixed in position normal to equatorial plane
N
Power input roller
Ω
Input roller axis fixed in position
K
P
Instantaneous axis of rotation of sphere
All instantaneous axes of rotation of sphere lie in plane thru input roller axis and center of sphere
O
P'
Small circle of contact between input roller and sphere
Small circle of contact between steering roller and sphere
S
Instantaneous axis of rotation of sphere must also lie in plane through steering roller axis and center of sphere
Steering roller
Steering roller axis set at angle A to input roller axis
A



ANGULAR VELOCITY RELATIONS

The direction of ω_b is determined by the steering roller angle A. ω_b has the component ω_i of known magnitude and direction and hence the magnitude of ω_b may be determined. Likewise $R_s\omega_s/R_b$ and ω_o are components of ω_b about axes parallel to the steering roller axis and the output axis respectively and thus have determinate magnitudes.

Ω = angular velocity of input roller
ω_i = angular velocity component of sphere parallel to input roller axis due to Ω
ω_b = instantaneous (total) angular velocity of sphere
ω_s = angular velocity of steering roller about its axis
ω_o = angular velocity component of sphere about output axis
θ_i = input roller angle
θ_o = output roller angle

$$\omega_i = \Omega \frac{R_i}{R_b}$$

$$\omega_b = \omega_i \sec \psi$$

$$\omega_s = \frac{R_b}{R_s}\,\omega_i \sec A = \Omega \sec A \text{ if } R_i = R_s$$

$$\omega_o = \omega_i \tan \frac{\pi}{4} \tan A = k\,\omega_i \tan A$$

or

$$d\theta_o = k \tan A\, d\theta_i$$

and

$$\theta_o = k \int \tan A\, d\theta_i$$

4 Questions About Control Timers:

1. HOW ARE THEY MADE?
2. WHAT KINDS ARE THERE?
3. WHERE ARE THEY USED?
4. HOW DO YOU SELECT ONE?

The following table answers question 1. Timer component parts are listed by function; characteristics and typical diagrams are included. The other considerations about timers—availability, applications, and selection factors—will be covered in the September issue of CONTROL ENGINEERING.

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A control timer is a device to control process functions on a time basis. It may be a simple time switch that opens or closes electrical circuits according to the time of day. Or it may be a program controller that introduces a series of time intervals into the operations of a process. For example, a time switch can operate factory work signals while a program controller can regulate the sequence, intervals, and rates of change of the operating variables for an automatic tire vulcanizer.

Control timers can be divided broadly into two types: single-interval, that times one interval and stops, and repeat-cycle, that repeats the interval over and over. But a better division is by function:

- Time switch—A 24-hr timing device that opens and closes electrical circuits according to the time of day on a continuous repeating schedule. A time switch that controls many operations is called a program timer.
- Time-delay relay—A device with a time lag between the energizing or de-energizing of the control circuit and the subsequent closing or opening of load circuits.
- Interval timer—Holds circuits open or closed for a given interval and then returns them to their original position. When energized, the load circuits or air pilot valves close or open, and remain so until timed out.
- Time-cycle controller—Opens and closes one or more circuits during a timed interval. This program controller can control a predetermined series of events in a preselected interval.
- Time-schedule controller—Regulates the value of a process variable (such as temperature) according to a predetermined time schedule. It is essentially an automatic controller with set point automatically adjusted during a preselected interval.

Next month's CONTROL ENGINEERING will discuss a large number of commercially-available timers that fall into these five functional classes. Application and selection will be handled then, too. But before considering the overall timer, let's look at its functions and the component parts that perform them.

Every timer must have:

- Timing means (measuring and driving)—Times and drives the unit. It determines the range and accuracy of the timer.
- Starting means—The manual or automatic impulse that initiates timing.
- Setting and control means—Actuates the load contacts and is adjustable to obtain the desired time intervals.
- Load contacts—Control the external circuits. Usually a form of electric or pneumatic switch. They link the timer and the controlled process.
- Indicating means—Gives a visual indication of elapsed time. Most timers have this except where period is not critical or seldom adjusted.

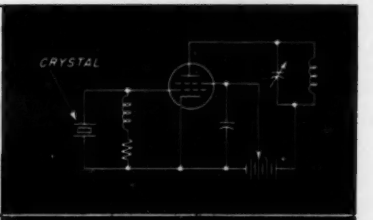
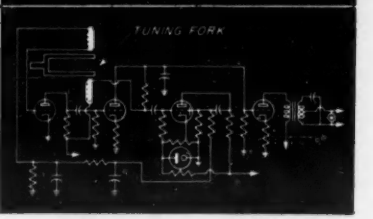
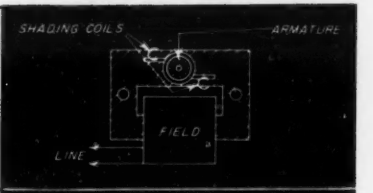
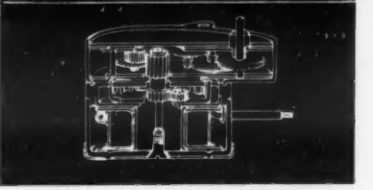
To help select an available timer or to build a special timer, you must be familiar with these functions and their comparative characteristics. This information is tabulated on the following pages.

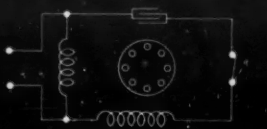
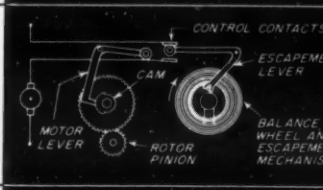
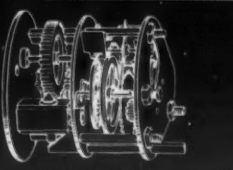
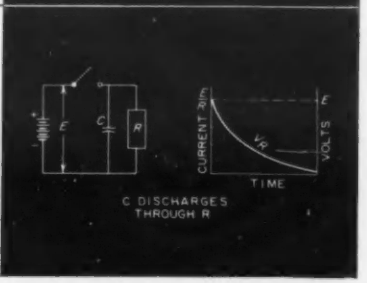
These articles are based on material to be published in the forthcoming "Instrumentation and Control Handbook", Douglas M. Considine, Editor-in-Chief, McGraw-Hill Book Co.

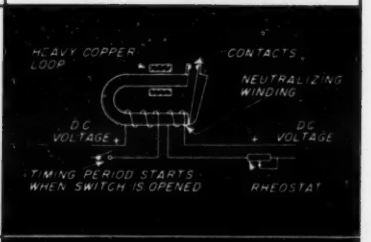
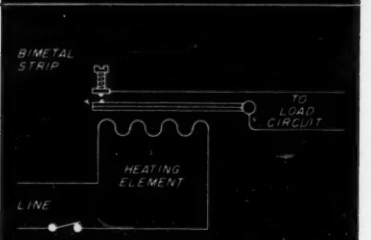
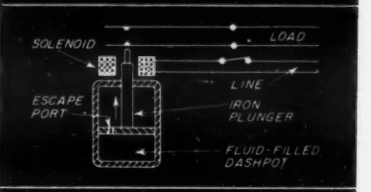
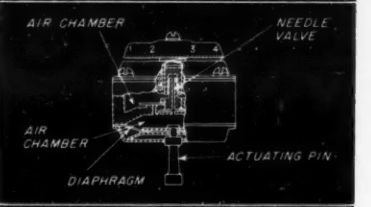
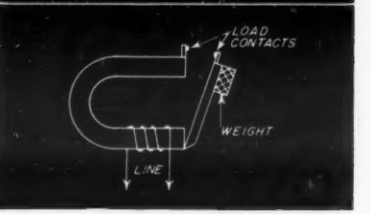
The author thanks the following concerns who supplied illustrations for this article: The R. W. Cramer Co., Inc.; Eagle Signal Corp.; The A. W. Haydon Co.; Seth Thomas Clock Co.; Taylor Instrument Co's.

THESE ARE THE BASIC TIMER COMPONENTS

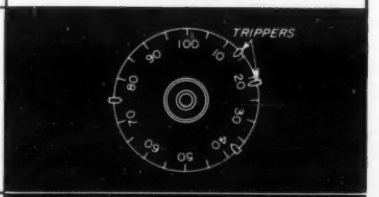
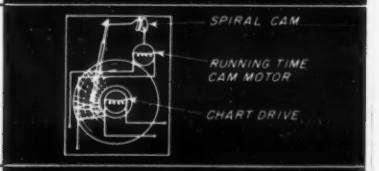
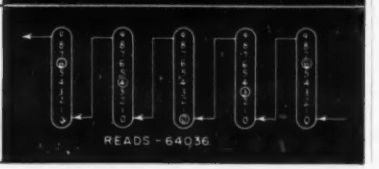
TIMING MEANS (Measuring and Driving)

	TYPE	COMMON RANGES	MINIMUM ERROR	CONTROL MEANS	TIMING ADJUSTMENT	REMARKS	DIAGRAMS
FREQUENCY GENERATORS	GENERAL	Used as precision standard when intervals are short (1 sec to 1 micro sec). If time is broken into minute parts, as in duration of a cycle in 100KC signal, and frequency is constant, it is only necessary to count the cycles in an interval to measure its length.					
	QUARTZ CRYSTAL OSCILLATOR	10 micro sec to 1 sec	1-10 micro sec	Control tube fires to operate relay	Switches set predetermined cycle count in gated counter circuit	Electronic multiplying and dividing circuits are added to give higher and lower frequencies, and output can be amplified. Errors are as low as 1 part in 10^8 if stable electronic components are used and temperature, humidity, barometric pressure, voltage, and loading are closely controlled.	
	TUNING FORK OSCILLATOR	1 sec to 30 min	10 microsec			Fork is driven by one electromagnet. Output is delivered to other electromagnet, which is excited by vibrating tines. Frequency can be changed as in crystal oscillator, or by clamping fork at different points. Output frequency can be constant within 1 part in 10^5 if ambient conditions listed above are constant.	
SYNCHRONOUS MOTORS	GENERAL	Synchronous motors, because of their inherent timing accuracy, are generally used to drive timers of greater than 1 min range. Motors count cycles and are as accurate as frequency of power source (instantaneous error of 60 cps is about plus or minus 0.1 cps). Outputs are normally between 2 and 75 in.-oz at 1 rpm. Speed not affected by ordinary voltage fluctuations. Time to reach synchronous speed can cause 2 cps timing error. For this reason clutches may connect continuously running motor.					
	SHADED POLE	1 sec to 1 week	0.01 sec abs. 2 sec/day			Squirrel-cage rotor. Copper shading coils produce supplementary flux, shifted in phase with main flux, to create starting torque. Nonreversible and can be stalled.	
	PERMANENT MAGNET					Salient pole with permanent magnet field. More efficient and higher torque than shaded-pole. Permanent magnet reduces coasting. Clutches, magnetic or dynamic braking, or large gear reductions are used with other motors to prevent coasting.	

INDUCTION MOTORS	1 min to 24 hrs	3-10 per cent	Dogs, notches, or cams operate contacts or valves directly or through levers; feelers on tape operate contacts.	Placing dogs, pins, keys on, or cutting notches in, dial or drum; adjustable cams, change gears, rotating arm or screw; variable radius pulleys or friction discs; punched, notched or embossed tape; interrupting circuit to electric motor for adjustable periods. Dc motors can be adjusted by varying series resistance either locally or remotely.	Used when controlled frequency is unavailable or high starting torque is required. Speed varies with load. Capacitor-start, capacitor-run, and shaded-pole types are most often used.	
DC MOTORS	1 sec to 4 hr.	5-10 per cent			Used on dc power and where timing must be controlled remotely. Constant speed dictates shunt-wound, but permanent magnetic are smaller and cheaper. Speed varies with voltage, load, and temperature. Voltage ranges from 4.5 to 115 v.	
REGULATED DC MOTORS	1 min to 24 hr.	0.1-1 per cent			One type uses centrifugal governor. Line contacts are opened when motor overspeeds. Unit shown here uses balance wheel and escapement. Pulses of line voltage are applied at regular intervals. Maximum error at 1 rpm is $\pm$0.1 per cent despite voltage variations of $\pm$20 per cent and load variations of 0–30 in.-oz. Principal problems are contact wear or failure and radio interference.	
SPRING ACTUATED DEVICES	Lever	Escapement			Intervals can vary from fractional sec to a month or more. Diagram shows lever-type escapement. Accuracy depends on precision of manufacture, temperature compensation, and external load. Pendulum escapements are bulky and only good for stationary service. Spring movements are limited by low and irregular torque.	
	1 sec to 1 week	0.2 sec/day to 5 sec/day				
	Pendulum	Escapement				
	12 to 24 hrs.	0.5 sec/day				
AIR MOTOR	1 hr to 24 hr.	0.3-3 per cent			Used in hazardous conditions. High speed air turbine drives a gear train regulated by escapement. Accuracy depends on constancy load and pressure. Typical characteristics: operating pressure 20-25 psig; air consumption 0.1 cfm; torque output 2-8 in.-oz at 1 rpm.	
CAPACITOR CHARGE OR DISCHARGE	0.1 sec to 1 min	1-5 per cent	Vacuum tube or Thyratron operates load directly or through relay; relay can also be operated directly through capacitor.	Variable resistor local or remote; switching different resistance or capacitance into circuit.	Uses time required for transient voltage and current changes in a resistance-capacity circuit. In circuit shown, capacitor discharge rate depends on RC product. After time RC, capacitor voltage drops to 37 per cent of initial value. V_R equals voltage across R. Timing is adjusted by varying resistance or changing capacity. Accuracy depends on constancy of charging voltage and component characteristics. If capacitor operates load directly, delay is limited due to required capacitor size. Using capacitor voltage to fire a gas tube overcomes this. Capacitor charging time can also be used.	

TYPE	COMMON RANGES	MINIMUM ERROR	CONTROL MEANS	TIMING ADJUSTMENT	REMARKS	DIAGRAMS
FLUX-DECAY RELAY	0.1 sec to 4 sec	5-10 per cent	Relay armature operates contacts.	Local: movable copper sleeve; local or remote: rheostat in series with neutralizing coil	Dc electro magnet has heavy copper ring or highly inductive short-circuited coil around the core, inside the main coil. When circuit opens, magnet drop-out is retarded by current induced in copper slug. Time constant, L/R of slug, determines delay.	
THERMAL DEVICES	1 sec to 8 min	5-10 per cent	Hot wire straightens bow, or heater bends bimetal to operate contacts.	Variable resistor in series with thermal element or adjustable contact; usually fixed.	Either ac or dc. Uses rate of expansion of metal or differential expansion of bimetal. Unit shown here uses bimetallic strip. If moving and fixed contacts are both mounted on bimetal strips, unit is temperature compensated. Heater is wrapped around moving bimetal. Another type (6-14 v range) has a wire attached to bent strip. Heat expands wire and contact on strip makes. Accuracy depends on ambient temperature voltage fluctuation and elapsed time between successive operations (for cooling). Units are cheap, silent, and not affected by positioner frequency.	
DASH POT	1 sec to 2 min	5-10 per cent	Solenoid armature operates contacts.	Usually fixed washer opens or closes bypass passages.	Ac or dc solenoid armature motion is retarded by fluid passing plunger. Repeatability requires constant viscosity fluid; therefore is affected by temperature changes. Silicone oils help between minus 30 and plus 120 deg F. For rapid recycling, quick-return check valves are used.	
PNEUMATIC DEVICES	0.1 sec to 5 min	5-10 per cent	Solenoid armature operates contacts.	Adjustable needle valve.	Uses time required for fixed volume of air to pass through a restriction. Armature of solenoid may be attached to a diaphragm. When solenoid is de-energized, spring-aided movement of diaphragm and armature is retarded by rate at which air flows through the restriction. Not affected by ambient temperature but air must be clean.	
INERTIA DEVICES	0.08 sec to 2 sec	5 per cent	Relay armature operates contacts.	Usually fixed; flywheel type may have adjustable stop pins.	Weights added to armature of ac or dc relays increase inertia and cause time delay. Where shock, vibration, or change in position affect operation, the armature can be coupled to a flywheel. Flywheel rotates as armature moves and inertia effect can be varied by changing its travel.	

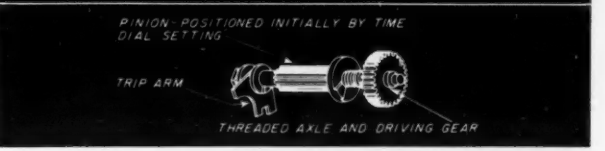
TIME INDICATING MEANS

TYPE	REMARKS	DIAGRAMS
DIAL	Dial can be fixed or movable. Some types have a pointer which is manually set at the desired time interval, plus a concentric pointer that rotates during timing to indicate remaining or elapsed time. Movable dials have functions other than mere indication. The time markings may be on a disc that carries trippers to operate contacts (see diagram), or on a knob that carries an arm to be actuated by the driving means at the end of a timed interval.	
RECORDER	Recorders plot a curve on a chart with time as one coordinate. Accuracy depends on uniformity of time graduations and constancy of chart speed. High-speed recorders, for very short intervals, use photographic film and a light source, or electro-sensitive paper and a stylus; others use pen and ink on round, strip, or drum charts.	
ILLUMINATED	High-speed short-interval units with crystal oscillators use illuminated read out. A series of lights indicates the time interval as a total number of cycles counted, as in a standard electronic counter. In the form of read-out indicated, a digit in each decade is illuminated to show the cycle count as it progresses. The right hand decade represents units, the next one tens, etc.	

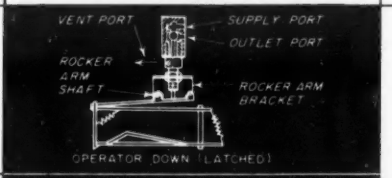
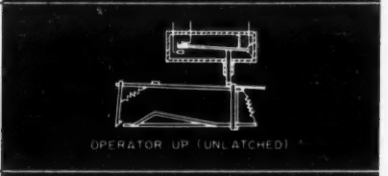
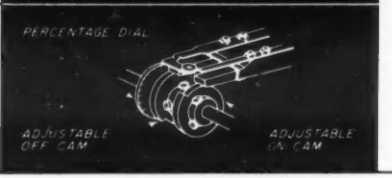
MEANS OF INITIATING TIMING

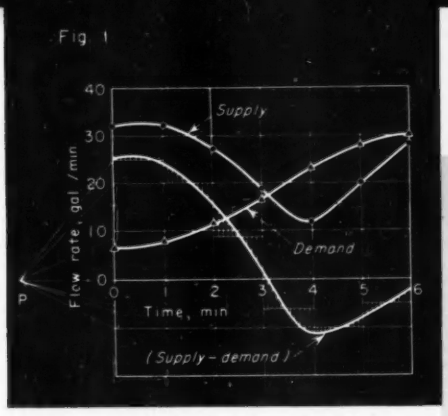
	TYPE	SPECIFIC REMARKS	GENERAL REMARKS
MANUAL STARTING METHODS	MOMENTARY ELECTRIC CONTACT	Push-button start for electrically driven timers with electromagnetic or cam-operated lock-in devices. Used with timers that stop at the end of each cycle, but whose operation is repeated regularly (stop-cycle timers).	Starting means selection factors: 1. Duration of interval—short intervals require automatic starting, since time for manual operation of pilot contact is long relative to interval measured. 2. Accuracy—automatic starting used where accuracy greater than plus or minus 0.1 sec is required. 3. Driving means—spring wound and simple electrical types are often started manually. Most electrical timers can be started manually or automatically. Air-motor units use quick opening valves.
	MAINTAINED ELECTRIC CONTACT	Closing a switch energizes driving or controlling means. Used on continuously operating (repeat-cycle) timers; can also be used on stop-cycle types, but switch must be opened at completion of timing to reset for new cycle.	
	SPRING WINDING	Some spring driven timers are started by turning a knob that winds the spring. Releasing the knob initiates timing. The same action, using a friction clutch and electric contacts, is used on simple electric-motor-driven models.	
	LEVER RELEASE	Used in stop watches and other spring-operated timers where spring is separately wound.	
AUTOMATIC STARTING	MOMENTARY ELECTRIC CONTACT	Used principally in single interval timing. An impulse from the event or process to be timed initiates timing.	
	MAINTAINED CONTACT	Used with continuously repeating timers. Contact is closed (or opened) by process or operation to be timed. In stop-cycle types, circuit must reopen before timer can repeat its cycle unless a suitable lockout is used.	

SETTING AND CONTROL MEANS

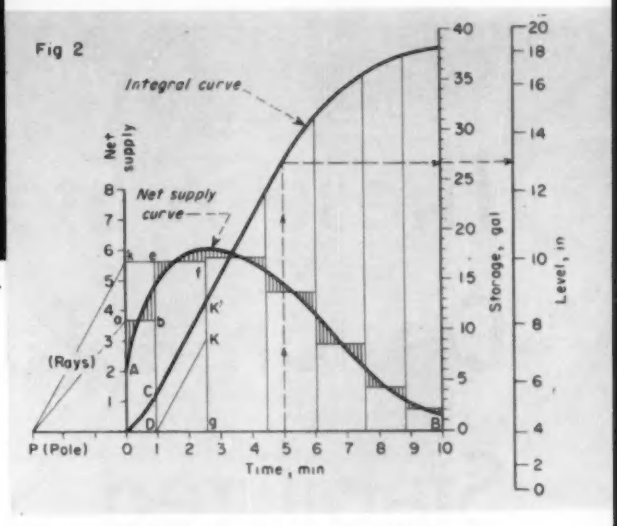
TYPE		REMARKS	DIAGRAMS
FOR MOTOR-DRIVEN TIMERS	SPEED CHANGERS	GENERAL: How timers are adjusted for the desired time intervals (setting means) and how the load contacts are actuated at the proper time (control means) depend primarily on the driving means. Common methods are itemized above under timing means (Measuring and Driving).	
	CAMS		
	DISCS AND DRUMS		
	THREADED AXLE AND PINION	Control means for accurate dial-type motor-driven timer with fine adjustment. Pinion is positioned on threaded axle according to desired time setting. During timing, the driving means rotates pinion. At end of travel, the pinion actuates an arm to operate load contacts. Time interval can be set to 0.1 per cent.	

LOAD CONTACTS

TYPE	SPECIFIC REMARKS	DIAGRAMS	GENERAL REMARKS
PNEUMATIC OPERATOR	Usually a small poppet valve. Diagram shows one operated by a latching mechanism. Trip pins, located at select spots on a motor-driven drum, alternately latch or release the hinged plates that move the valve plunger.		Usually consist of some form of electric or pneumatic switch arrangement. Some common configurations for motor-driven timers are shown to the left. Timers that are not motor driven usually depend on the armature of a relay or the plunger of a solenoid to operate the control contacts. Some electronic types develop enough current to operate a load connected in series with the plate circuit of a control tube. Also, some thermal types do not require auxiliary relays.
ELECTRIC OPERATOR	Contacts can be closed, open, or mercury tube, and can be found in a variety of current ratings, number of poles, and operating sequences. The latching-type operator is shown with a SPDT snap-acting switch.		
CAM OPERATED	Switch plungers or contact leaves ride directly on cams. Cams shown here are separately adjustable. On and off points and interval between operations can be adjusted.		



Transient records of a tank's supply and demand.



Construction of pole-and-ray graphical integration.

Graphical Integration By Pole-and-Ray

H. M. Paynter's February article, "How to Analyze Control Systems Graphically", prompted enthusiastic reader feedback. Here is one reader-author's alternate method. Note that effects of valve characteristics, load changes, and automatic proportioning are not shown.

A. S. LEVENS, University of California, Berkeley

The supply and demand records of a storage tank are shown in Figure 1. Plotting the difference between them develops the (supply—demand) curve. The "pole-and-ray" method explained in this note readily takes the time integral of the (supply—demand) curve to develop the storage curve. Figure 2 demonstrates the method.

Consider the area under the net supply curve in Figure 2. Divide the area into strips whose widths depend on the steepness of the curve. Assume a pole distance OP equal to three units (it could be any convenient distance) of the horizontal scale. The rectangle $OabD$ approximates the area of the first strip. Line ab is positioned by eye so that the shaded areas are about equal. Rays such as Pa are drawn through point P. Line OC is drawn through point O parallel to Pa. The following verifies that the area of the first strip equals $\overline{CD}$ times $\overline{OP}$:

1. Triangles aOP and CDO are similar, by construction.
2. Then $\frac{CD}{DO} = \frac{aO}{OP}$
3. $\overline{CD}$ times $\overline{OP}$ = $\overline{DO}$ times $\overline{aO}$.
4. $\overline{DO}$ times $\overline{aO}$ is the rectangular area equivalent to the area of the first strip.
5. Therefore, $\overline{CD}$ times $\overline{OP}$ equals the area of the first strip.

The area of the second strip is found in similar fashion. Line DK is drawn parallel to ray Pk. The area of this strip equals $\overline{Kg}$ times $\overline{OP}$. If a line is drawn through point C parallel to DK, distance $K'g$ equals $CD + Kg$. Therefore, the sum of the areas of the first and second strips equals $\overline{K'g}$ times $\overline{OP}$. Note that it is not necessary to draw DK, since CK' can be drawn parallel to ray Pk. Repeating this process for the other strips and drawing a smooth curve through points O, C, K', etc., establishes the "integral curve". It determines the area of any portion of the total area under the given curve, and therefore the storage.

The level scale shown at the far right of the figure is non-linear to take into account the storage vessel's shape. The scale is positioned according to the initial level at zero time. Level now reads directly at any time interval.

These 7 Steps Design a Tach Stabilized Servo

1 SELECT MOTOR-GENERATOR
2 SPECIFY GEAR RATIO
3 DETERMINE DESIGN CONSTANTS
4 FIND VELOCITY ERROR CONSTANT
5 CALCULATE GAIN AND FEEDBACK
6 CALCULATE ALLOWABLE BACKLASH
7 CORRECT FOR QUADRATURE AND PHASE SHIFT

THE GIST: Low power instrument servos are widely used to transmit angular data. And since position, not power, is transmitted, the load inertia and friction can be neglected. Performance thus depends almost entirely on the internal characteristics of the servo.

Servos of this type are often used in aircraft and analog computer instrumentation. They often use two-phase motors stabilized with ac tachometers, a simple arrangement since motor-generator units can share the same housing and the same shaft. Most tachometer-stabilized instrument servos can be designed along logical lines. This article details this step-by-step procedure and develops an example to show how it's followed.

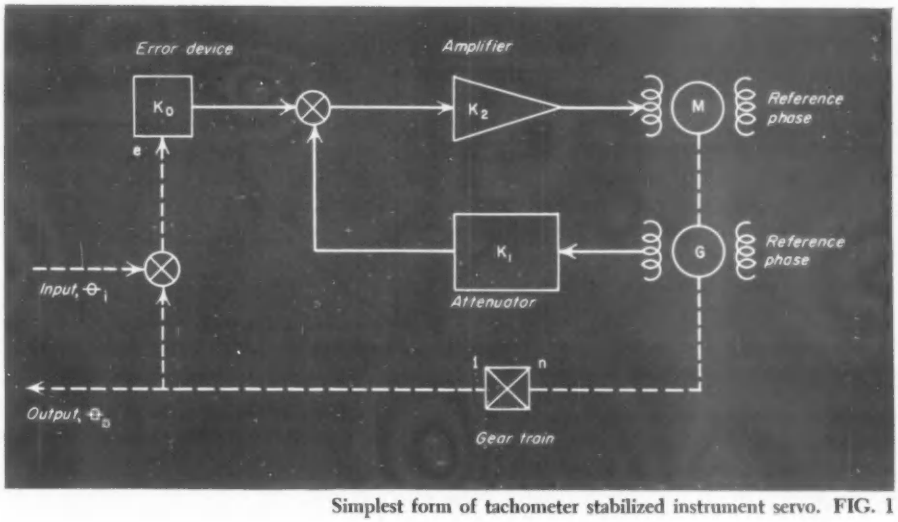
JULES E. KADISH, Electronics Div., American Machine & Foundry Co.

A tachometer stabilized servo is shown in Figure 1. The amplified signal from the error detector, K_a, energizes the motor to drive the output shaft, θ_o, into angular correspondence with the input shaft, θ_i. Thus the system transmits angular data.

The tachometer generates a signal proportional to the rate of change of position of the output shaft. This rate voltage is combined with the displacement error voltage and the difference is fed to the amplifier. With high gain, a small difference between the rate and displacement voltages causes full torque on the motor. The direction of the torque depends on the relative magnitudes of the two voltages.

The displacement voltage drives the motor towards the null at a speed that results in a rate voltage slightly smaller than the displacement voltage. The displacement voltage decreases as the null is neared.

With high motor inertia, the displacement voltage can fall below the rate signal. Then the phase of



Simplest form of tachometer stabilized instrument servo. FIG. 1

the amplified voltage will reverse. The motor torque will also reverse and oppose the inertia torque enough to slow down the motor to a speed corresponding to the displacement. If the rate voltage is insufficient to brake the inertia load to a stop at the null, the system will overshoot. The tachometer stabilizes the system by applying a torque proportional to motor speed and in the opposite direction. It is mathematically analogous to viscous drag.

One phase of the motor and one phase of the tachometer are connected to a reference voltage source. In addition, a 90 deg phase shift is required between the two motor phases. This is normally produced by networks within the amplifier.

Many manufacturers make 60 and 400 cps motor-generators suitable for this servo. The output torque at stall varies from ¼ to 7 oz-in. and the no-load speeds from about 3,000 to 12,000 rpm. Motor ratings range from 3 to 10 watts. These drag-cup tachometers have an output voltage proportional to shaft speed with the frequency of the supply.

When an instrument servo is to be designed, the known parameters are usually:

- maximum required shaft speed of output member
- maximum allowable steady state following error (velocity lag)
- maximum allowable static error

There are other factors, such as allowable acceleration error, frequency response, and load characteristics, but in most instrument servos these are secondary considerations.

By following the design procedure, specifications can be obtained for:

- servo amplifier gain
- parameter of tachometer feedback network, including required phase shifting network
- allowable gear train backlash
- gear ratio, motor to output member

After determining these factors, a servo can be constructed that will satisfy the known parameters given above. Actually, the following steps are only good for designing a relatively low-performance servo.

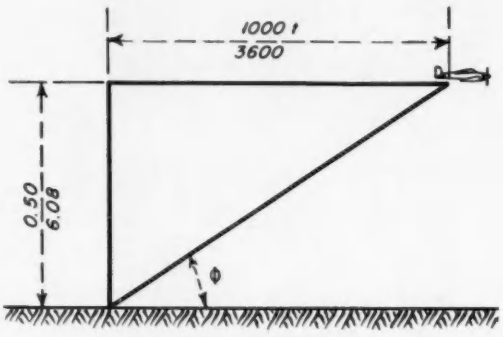
In a tach feedback servo such as the one described here, two variables must be determined once the motor-generator and gear train have been chosen. These are the amount of tachometer feedback and the amplifier gain. The two variables, which will be fixed in order to determine feedback and gain, are K_v and M_p (defined in Steps 4 and5). Once K_v and M_p are chosen, feedback and gain can be calculated. The servo bandwidth can then be found.

STEP 1—
SELECT MOTOR-GENERATOR

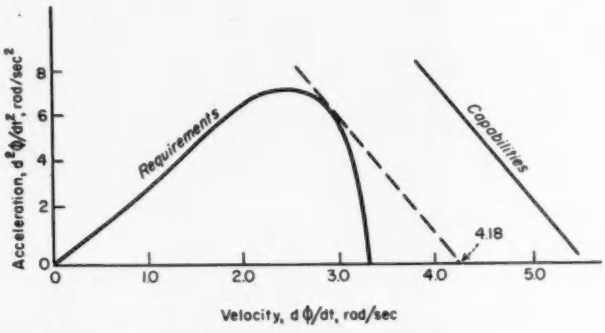
In most instrument servos, the ratio of stall torque to rotor inertia is the figure of merit that governs selection of the motor. In addition, although starting friction forces in a gear train often are difficult to evaluate, the stall torque of the motor must exceed its starting friction, a factor of ten being commonly used. Thus the motor should have a high figure of merit and a stall torque at least ten times greater than gear train starting friction.

The maximum operating motor speed usually is its speed at maximum power output. The ratio of this speed to maximum speed of the output member defines n, the gear ratio. As shown in the next step, there are other considerations in selecting the gear ratio. But this estimate will suffice to check for sufficient stall torque.

For example, assume that a servo uses a multiturn potentiometer as the output member. Five oz-in. of starting torque are required and the maximum output speed is 120 rpm. Maximum motor speed is 6,000 rpm so that the gear ratio n is 50. The friction torque reflected to the motor shaft is 0.1 oz-in. and the available motor stall torque 1.0 oz-in., giving a satisfactory safety factor of ten.



Trigonometry of radar following system showing ground viewing station and a plane. FIG. 2



System acceleration versus velocity, showing the requirements of the system and the capabilities of the motor and gear train. FIG. 3

STEP 2 — SPECIFY GEAR RATIO

A servo must be able to follow its input at maximum input velocity. Input acceleration is generally some function of this velocity, and the motor-generator and gear train must be able to accelerate the output member at the required rate while rotating at desired velocity. These requirements are met by specifying the correct gear ratio between the motor-generator and the output.

At any motor speed with full voltage on the motor a certain amount of torque is available to accelerate the rotor plus all reflected inertias. This torque value can be obtained from the torque-speed characteristics of the motor. Then a curve of output member acceleration versus its velocity can be plotted. Neglecting friction,

$$\text{motor acceleration} = \frac{\text{torque oz-in.}}{\text{inertia oz-in.-sec}^2}$$

NOMENCLATURE

θ_i = input angle, radians
θ_o = output angle, radians
e = error, $(\theta_i - \theta_o)$, radians
n = gear ratio, motor shaft to output member
t = time, seconds
S = Laplacian operator
V = motor voltage on variable phase, volts
J = inertia at motor shaft, oz-in-sec² (including reflected load
T = torque at motor shaft, oz-in.
dT/dV = motor torque voltage constant, oz-in./volt
dT/dw = motor torque speed constant, oz-in./radian/sec
w = angular velocity of output shaft, radians/sec
M_p = amplitude ratio, θ_o/θ_i at its maximum value
K_o = error voltage constant, volts/radian error
K_1 = tachometer voltage constant at the tachometer shaft (after attenuation by a suitable network), volts/radian/sec
K_2 = amplifier gain

The acceleration and angular velocity of the output member are $1/n$ times that of the motor. If the servo under design has certain maximum acceleration requirements, a curve of these requirements can be plotted on the same coordinates as the capabilities curve mentioned above. Then the latter must enclose the requirements curve. The particular motor-generator and gear ratio chosen ensures such enclosure, as well as smooth starting (high stall torque to starting friction ratio).

Here's an example: an automatic following radar system contains a servo that must be capable of following the elevation angle of an aircraft flying directly overhead. The maximum speed is 1,000 knots and the minimum altitude is 500 ft. The angle of the output shaft is equal to the elevation angle from radar to aircraft. Determine motor to output shaft gear ratio to meet specifications.

Figure 2 shows the trigonometry of the situation, where ϕ is the elevation angle in radians and t is the time in seconds. In t sec, the maximum distance the aircraft moves from the overhead position is $1{,}000t/3{,}600$ nautical miles. The minimum altitude is $0.5/6.08$ nautical miles. Therefore

$$\cot \phi = \frac{1{,}000t/3{,}600}{0.5/6.08} = 3.38t$$

$$\frac{d\phi}{dt} = -3.38 \sin^2 \phi$$

$$\frac{d^2\phi}{dt^2} = -3.38 \sin 2\phi \, \frac{d\phi}{dt}$$

Since both $d\phi/dt$ and $d^2\phi/dt^2$ are functions of ϕ, it is possible to plot $d^2\phi/dt^2$ as a function of $d\phi/dt$, Figure 3.

A typical motor-generator that might be used for this application has a torque-speed curve and rotor inertia that permit an acceleration-speed curve as in the equation

$$\text{acceleration} = 5{,}850 - 5.32\, d\phi/dt \text{ radians/sec}^2$$

The maximum speed (zero torque) of the motor is then 1,100 radians/sec. The slope of the acceleration-velocity curve is minus 5.32. To just enclose the requirements curve, the zero-torque speed of the output member must be 4.18 radians/sec. Since the zero-torque speed of the motor is 1,100 radians/sec, the gear ratio is 1,100/4.18 or 264. With a 25 per cent margin this ratio is 198, say 200.

STEP 3 — DETERMINE DESIGN CONSTANTS

After choosing the motor-generator and gear ratio, determine their various constants. Among these: inertia at the motor shaft, the torque-voltage constant, and the torque-speed constant.

The inertia, J, at the motor shaft consists mainly of the rotor inertia of the motor-tachometer. Pinion teeth cut directly on the motor shaft will help reduce this value. The initial gear train design permits a fairly accurate estimate of this contribution to the inertia. Gear inertias are referred to the motor shaft and vary as the inverse square of the gear ratio between them and the motor. Units: oz-in.-sec^2.

The value of the torque-voltage constant, dT/dV, is obtained from the stall-torque versus voltage curve of the motor. If this curve is not available, the value can be taken as the full voltage stall torque divided by the full voltage. Units are oz-in./volt.

The torque-speed constant, dT/dw, is obtained from the manufacturer's data. A tangent drawn through the point of usual operating speed will give this constant. If no curve is available, it can be considered equal to the negative ratio of stall torque to synchronous speed. Units: oz-in./radian/sec.

Certain other constants not associated with the motor characteristics must be determined before proceeding with the design. These are error-voltage constant, maximum output speed, maximum following error, allowable velocity error constant and allowable acceleration error constant.

The maximum output member speed, $d\theta_o/dt_{max.}$, and the maximum allowable following error, $e_{max.}$, are usually known from the specifications of the servo. The error-voltage constant, K_o, depends on the error device. It equals the slope of the error voltage versus error (in radians) curve at zero. Units are volt/radian.

The velocity error constant, K_v, is the ratio of $d\theta_o/dt_{max.}$ to $e_{max.}$ Units are sec^{-1}. The acceleration error constant, K_a, is the ratio of $d^2\theta_o/dt^2$ to e at $d\theta/dt$ equals zero. Units are sec^{-2}.

STEP 4 — DETERMINE VELOCITY ERROR CONSTANT

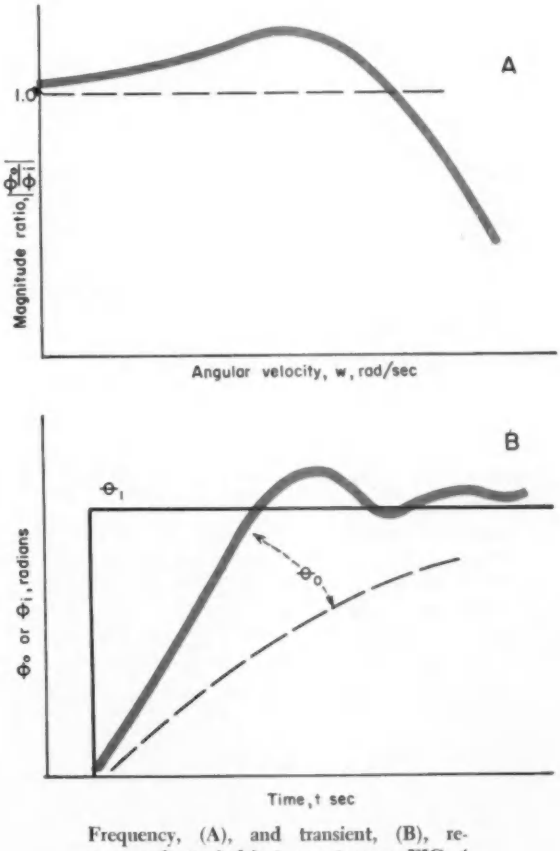
The system velocity error constant, K_v, is defined as the ratio of output shaft speed to output shaft error under constant speed conditions. The higher this constant, the smaller is the following error for a given shaft speed. But there are limits to the maximum K_v that should be specified. Values of K_v up to 200 can be realized, but other compensating means besides tachometer feedback are required to achieve this high value. Instability can result if gear train backlash exceeds allowable values or if there are phase shift contributions from the high gain amplifiers.

To reduce gain and anti-backlash requirements, K_v is chosen as low as possible consistent with accuracy requirements. If the K_v value is too low, the calculated value of K_1 may be so high that the tachometer output would have to be amplified instead of attenuated. This is undesirable. Another factor that demands and defines a low value of K_v is a certain gain K_2. This gain should be high enough so that the static error caused by starting friction is not excessive. At zero speed

$$V = K_o K_2 e$$

The motor starting voltage can be determined for a given starting friction. This is approximately

$$V_o = \frac{\text{static friction (oz-in.)}}{dT/dV}$$



Frequency, (A), and transient, (B), response of a typical instrument servo. FIG. 4

For a given gain K_2, the static error is

$$e_s = \frac{V_o}{K_o K_2}$$

If the starting friction torque of the gear train is considered negligible, V_o can be taken as 20 per cent of full motor voltage.

STEP 5 — CALCULATE GAIN AND FEEDBACK

If the input angle θ_i varies sinusoidally with time, the output angle θ_o will follow, but magnitude and phase errors will exist. Figure 4(A) shows a plot of the ratio θ_o/θ_i versus w, the angular velocity. The magnitude ratio will be unity at w equals zero. It may rise above unity as the frequency increases, and then will fall.

The frequency response and transient response of the system are intimately related. The transient response, Figure 4(B), is the response versus time of θ_o for a sudden fixed displacement of θ_i. If the frequency response has a pronounced peak, the transient response may be oscillatory or the output oscillations may take excessively long to reach zero. But some overshoot and small amplitude highly damped oscillation is often desirable—partially because of the reduced settling time.

For good servo operation, the maximum value of θ_o/θ_i, M_p, should be kept within the range of 1.1 to 1.5. The higher value of M_p permits lower amplifier gain and greater gear backlash, but gives less stability margin. However, a lower value of M_p results in a servo with greater frequency capabilities and a larger acceleration error constant. Where the acceleration error requirements are not critical, a value of M_p of 1.3 is often used. A value lower than 1.1 can result in too small an overshoot.

Another velocity error constant, K_u, depends on the value of M_p that is chosen.

$$K_u = \frac{M_p^2 + M_p\sqrt{M_p^2 - 1}}{2}$$

For an M_p of 1.3, K_u is 1.38. Once K_u is determined, the amplifier gain, K_2, and the tachometer attenuated output, K_1, can be calculated with the following equations:

Tachometer output,

$$K_1 = \frac{K_o}{nK_v}\left[1 + \frac{K_u\, dT/dw}{JK_v}\right] \text{ volts/radian/sec at tachometer shaft}$$

Amplifier gain,

$$K_2 = \frac{K_v^2 nJ}{K_o K_u (dT/dV)}$$

After determining this gain, the static friction error should be checked (Step 4) to make sure it is small enough. If it is not, a compromise value of K_v should be tried and the calculations made again.

The acceleration error constant, K_a, is given by

$$K_a = \frac{K_o K_2\, dT/dV}{Jn}$$

This value, the ratio of output acceleration to output error at zero velocity, is the square of the natural resonant angular velocity of the system.

STEP 6 — CALCULATE ALLOWABLE BACKLASH

In addition to the mechanical error, backlash can also cause instability that results in gear chatter. With backlash in the gear train, the motor responds to an error in one direction without reduction in voltage until the backlash is taken up. The error device may overshoot the zero error position and the motor receive a reverse command. The dither error voltage resulting from backlash enters the amplifier and may reduce effective amplifier gain because of saturation effects.

A small amount of dither in a system is often desirable, but it is difficult to control this by controlling the backlash. For this reason, a limit is usually placed on the allowable backlash.

Specify the backlash so that an error of half the backlash angle is insufficient to start the motor. With the gear train starting friction known, the motor starting voltage can be determined. (For this calculation, ten per cent of the full motor voltage is a reasonable value to use as its starting voltage.) Whatever angular error produces this voltage is the maximum allowable half backlash angle.

If the total backlash angle at the error device is e_b radians and the motor starting voltage is V_s, then

$$e_b = \frac{2V_s}{K_o K_2}$$

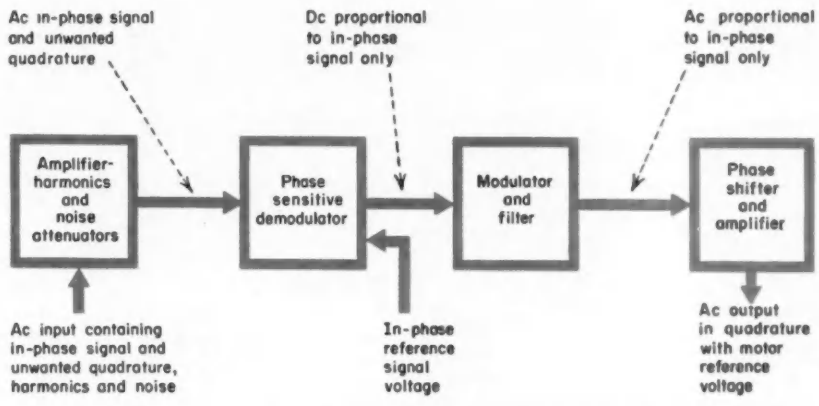
The allowable backlash angle should not exceed the expected static friction error. Usually the backlash is measured at the motor shaft where the backlash angle is approximately multiplied by the gear ratio. With relatively high K_v systems, K_2 is large and the allowable backlash angle is small. Higher precision gears or even anti-backlash gears may be required.

These relations are not to be considered rigorous, but just an indication of the allowable backlash.

STEP 7 — CORRECT FOR QUADRATURE AND PHASE SHIFT

The reference voltages for the motor and tachometer are normally supplied from signal transformers. The tachometer output voltage may be in phase with its reference voltage, but often it is not. Harmonies and noise are present in the tachometer output. If the fundamental output phase leads the reference voltage phase, a lag network of series resistance and shunt capacitance can correct for this phase lead, as well as help attenuate the unwanted harmonics and noise.

The error device can introduce a considerable phase shift between its output voltage and its reference voltage. In a typical system, a 400 cps synchro


Ac in-phase signal and unwanted quadrature
Dc proportional to in-phase signal only
Ac proportional to in-phase signal only
Amplifier-harmonics and noise attenuators
Phase sensitive demodulator
Modulator and filter
Phase shifter and amplifier
Ac input containing in-phase signal and unwanted quadrature, harmonics and noise
In-phase reference signal voltage
Ac output in quadrature with motor reference voltage

Demodulator-modulator system for cancelling the unwanted quadrature, harmonic and noise components of a signal. FIG. 5

generator connected to a differential generator which, in turn, connects to a control transformer, can cause the output voltage from the transformer to lead the synchro voltage by as much as 36 deg.

Since the tachometer attenuated output is subtracted from the error device voltage, both outputs should be in phase or quadrature components will exist. The in-phase amplifier input components are phase-shifted in the amplifier until the amplifier output voltage is in quadrature with the motor reference voltage. Unfortunately, the quadrature amplifier input components are phase-shifted by the same amount and end up in phase with the motor reference voltage. This contributes to motor heating but does not help develop motor torque.

A worse condition can exist in high gain amplifiers, where the quadrature component actually saturates several amplifier stages, rendering them inoperative. This can happen in a potentiometer system where the in-phase component from the feedback potentiometer cancels the in-phase component from the input potentiometer. What is left is a residual quadrature component instead of a complete null.

Phase shifting networks are used to control this quadrature. A usual requirement is that the undesirable amplifier output voltage be no greater than 40 per cent of full motor voltage. If phase-shifting networks are unsatisfactory, a demodulator-modulator system can prevent amplification of the quadrature and noise; but odd harmonics (often present as residual voltage from the tachometer or synchro) will cause an effect similar to an error voltage unless they are properly suppressed.

With this system, Figure 5, the total amplifier input signal is demodulated from in-phase and quadrature ac to dc by a phase sensitive demodulator. The in-phase signal (and any unwanted odd harmonics) is converted to dc with a magnitude and polarity dependent on the magnitude and phase of the in-phase signal. Then the dc is modulated into an ac voltage. This can then be amplified and phase shifted until it is in quadrature with the motor reference voltage. The demodulator and modulator can contribute appreciable phase shift.

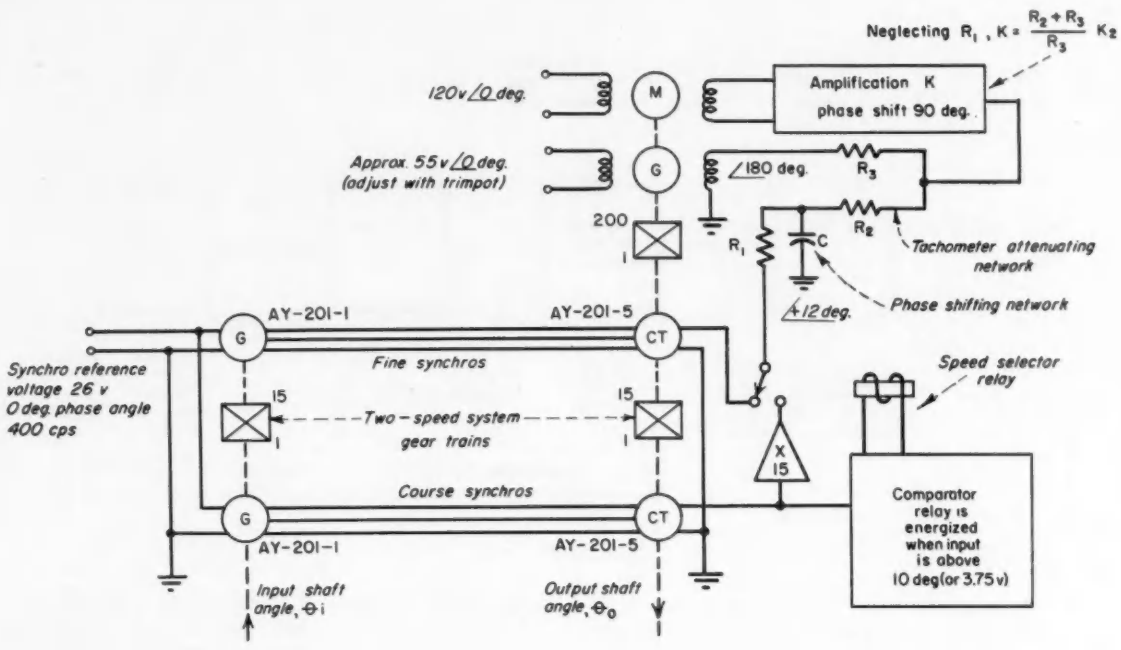
HOW TO USE THESE STEPS

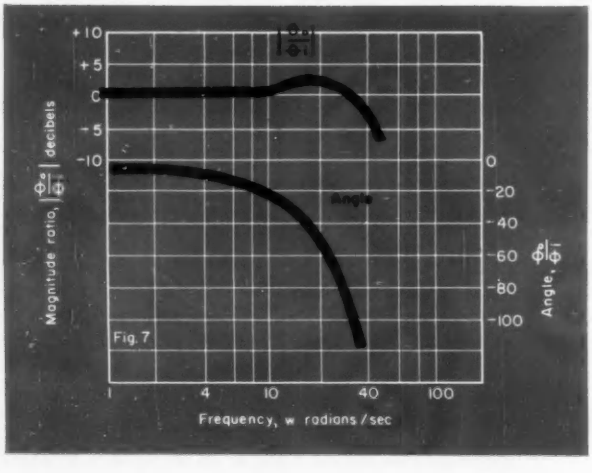
To show how these techniques can be applied in designing an instrument servo, assume that a remotely located shaft is to follow the angular position of another shaft to an accuracy of plus or minus ½ deg. The motor-generator selected is a 400 cps Kollsman 1333–0460322 and the acceleration-velocity considerations demand a gear ratio of 3000:1. Motor and gear ratio selection follow the procedures outlined for the examples in Steps 1 and 2. The maximum required output shaft speed is 2 rpm.

Eclipse-Pioneer synchros are the error detectors. When using a AY—201-1 synchro transmitter with a AY—201-5 control transformer, the synchro error itself is ½ deg. Since required system accuracy is ½ deg, this leaves no margin for following errors and other inaccuracies. Thus a two-speed synchro system must be used. This is shown in Figure 6.

The 15:1 gear ratio between the fine and coarse synchros is common. The fine synchro error is ½ deg, giving an output error of ½ times 15 or 1/30 deg. Thus the overall error will consist primarily of the velocity lag and static errors. Some margin is left if the maximum following error of the coarse synchro is limited to ⅓ deg.

The coarse synchro error is zero at two angular positions of the output shaft. But one of these





A SERVO AND ITS RESPONSE

The typical instrument servo uses a two-speed synchro system for increased accuracy. Its frequency response plot shows magnitude ratio and phase angle as a function of frequency.

nulls is unstable and a small error will tend to drive the motor in a direction to increase the error from this null. The other null, 180 deg removed from the first, is stable in that an error will drive the motor in a direction to decrease this error.

The fine synchro's 15:1 gear ratio gives it fifteen stable nulls. Some system is required to ensure the choice by the servo of the one correct stable null. The comparator does this by selecting the coarse synchro output if the coarse synchro error is excessive. Because of the 15:1 gear ratio, the comparator relay should close at a coarse synchro error of less than plus or minus 12 deg. In Figure 6, it operates at a 10 deg error. The odd gear ratio between the coarse and fine synchros prevents 180 deg ambiguity.

The 15:1 amplifier connected to the coarse synchro output assures the same error voltage at the selector relay from both the coarse and fine synchro when the error is near zero. The synchros are adjusted so that when the error from the coarse control transformer is zero, the error from the fine control transformer is also zero. In addition, when a small angular error exists at the output shaft, the phase of the error voltage from each control transformer must be the same.

In accordance with the procedure outlined in Step 3, determine the system design constants.

J = total inertia at motor shaft
= 1.71×10^{-4} oz-in.-sec^2
dT/dV = torque-voltage constant

$= 8.33 \times 10^{-3}$ oz-in./volt

dT/dw = torque-speed constant
$= -7.95 \times 10^{-4}$ oz-in./rad/sec

n = gear ratio to coarse synchro
= 3,000:1

K_o' = error-voltage constant at coarse synchro (before attenuation by phase-shifting network and including the 15:1 amplifier)
= 322.5 v/radian

$d\theta_o/dT_{max.}$ = maximum output speed
= 2 rpm or 0.21 radian/sec

e_{max} = maximum following error
= $\frac{1}{3}$ deg or 0.00582 radian

K_v = velocity-error constant
= 0.21/0.00582 or 36

The condenser-resistor network, consisting of C and R_1, corrects for the 12 deg inherent phase shift in the synchros. For this 12 deg phase shift, tan 12 deg equals R_1/X_c. Try C equal to 0.005 uf or 79.6K at 400 cps. Then, neglecting R_2, R_1 equals 79.6 tan 12 deg or 16.9K. Use R_1 equals 16K. The attenuation caused by the phase-shifting network is cos 12 deg or 0.978. Therefore K_o equals $0.978K_o'$ or 315 v/radian.

Assuming that M_p equals about 1.3 is a design objective, then K_u equals 1.35. With this information, K_2, the amplifier gain, can be calculated.

$$K_2 = \frac{K_v^2 nJ}{K_o K_u \, dT/dV}$$

$$K_2 = 187.5$$

K_1, the tachometer attenuated output, is also determined.

$$K_1 = \frac{K_v}{nK_v}\left[1 + \frac{K_u \, dT/dw}{JK_v}\right]$$

$$K_1 = 0.24 \times 10^{-2} \text{ volts/radian/sec}$$

The tachometer output voltage is 1.44 v/1,800 rpm or 0.764 x 10^{-2} v/radian/sec. Assume an R_2 much greater than X_c to prevent loading X_c. Say R_2 equals 1 meg. Than to calculate R_3.

$$K_1 = \frac{(\text{tachometer output})(R_1 + R_2)}{R_1 + R_2 + R_3}$$

$$R_3 = 2.22 \text{ meg; use 2.2 meg}$$

Since the exact output voltage of the tachometer is seldom known, a trimpot on the reference voltage supply to the tachometer can be used to obtain the required K_v. The total amplifier gain for this system, K, can be calculated now

$$K = K_2 \frac{(R_1 + R_2 + R_3)}{R_3}$$

$$K = 274$$

The allowable backlash is given by

$$e_b = \frac{2V_s}{K_o K_2}$$

with the starting voltage, V_s, estimated as 20 per cent of full voltage or 24 volts.

$$e_b = 0.0466 \text{ deg}$$

Spring-loaded anti-backlash gears are probably required between the fine and coarse synchros and, also, for one or two gears near the fine synchro between the fine synchro and the motor.

The static error is approximately equal to 0.0466 deg. This is satisfactory. The 0.0466 deg error is the theoretical one that can be allowed at the coarse synchro. But the servo normally operates from the fine synchro which can have allowable backlash of 15 times as much, or approximately 0.7 deg.

This system will yield a certain magnitude ratio characteristic as a function of frequency. This can be determined from a logarithmic plot of the frequency response.

$$\frac{\theta_o(jw)}{e(jw)} = \frac{K_v}{jw\left[\dfrac{Jjw}{K_1K_2\dfrac{dT}{dV} - \dfrac{dT}{dw}} + 1\right]}$$

$$\theta_i - \theta_o = e$$

$$\frac{\theta_i(jw)}{\theta_o(jw)} = \frac{jw\left[\dfrac{Jjw}{K_1K_2\dfrac{dT}{dV} - \dfrac{dT}{dw}} + 1\right]}{K_v} + 1$$

$$\frac{\theta_o(jw)}{\theta_i(jw)} = \frac{36}{jw[3.77 \times 10^{-2}jw + 1] + 36}$$

This last equation is plotted in Figure 7. The curve of θ_o/θ_i has a maximum value of 1.3 (2.28 db). This is in accordance with the design objectives. The peak occurs approximately at the frequency where 3.77×10^{-2}w equals one, 26.5 radians/sec or 4.23 cps. This completes the design of the system since all specifications are satisfied.

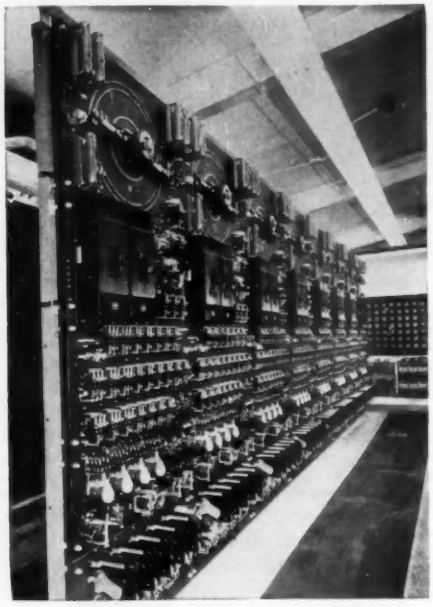
Sylphon In The USSR

In our May issue, page 69, the word "sylphon"—cognomen for a prominent American bellows manufacturer—was linked to the Norse goddess of the atmosphere. Recently, a letter came to us from Max Studley of New York that reveals even more practical use for the dulcet word. It seems that Studley, while translating a Bristol Co. catalog into Russian, needed a word for *bellows*. He checked with several Russian "Kip" (instrument) engineers. Sure enough, the universally accepted Russian word for bellows was sylphon.

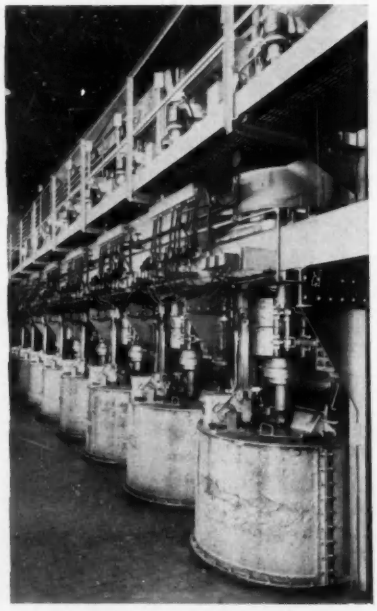
Controlled Acceleration and Braking Get the Most From Centrifuges

Sturdy components that are routine controllers for heavy industry often can be hooked together for sophisticated jobs. Witness this ingenious variable programming system (Figure 1) in a sugar plant.

W. K. Klager, Cutler-Hammer, Inc., Milwaukee, Wis.



Control panels for automatic control extend from the left to rear center in this picture. On the far wall are the process timers (above) and the discharge timers and battery control equipment (below). FIG. 1



Battery of eight sugar centrifugals recently installed at National Sugar Refining Co. Baskets are at the bottom and the air applied brakes are on a level with the push-buttons. The main drive motors are at the top (just below the cat-walk grating). FIG. 2

Program control optimizes product output, reduces power demand, and recaptures normally-wasted energy during operation of this battery of eight raw sugar centrifugals (Figure 2). A unique arrangement guides each machine independently, while a master controller for the battery corrects variations in individual batches and properly sequences all machines.

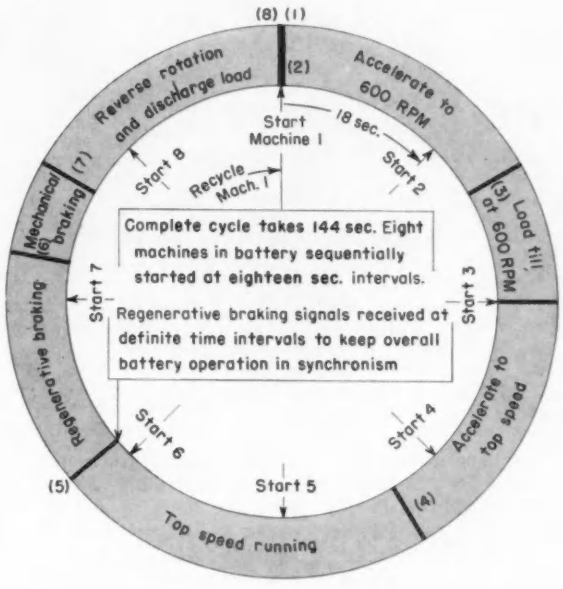
The process raw sugar is batch-loaded into a large, perforated, metal basket and centrifuged at high speed to throw off the molasses film adhering to the crystals. Sugar spinning involves many steps, as shown in the process diagram (Figure 3). Battery operation requires constant overall cycle time to keep each machine in sequence, but limit switch operations and process variations in certain steps cause time modifications. The master control, therefore, initiates sequenced signals to start regenerative braking of each machine at definite intervals, adjusting the top speed running time (a non-critical step) to maintain a fixed time cycle.

The main drive motors are an integral part of the control system and must be brought to top speed at a rate depending on the quality of the batch. Uniform acceleration to 1,200 rpm (top speed) is obtained through a combination of shunt field-weakening and step-wise increase of the armature voltage. With the motor field fully excited, the armature is connected to the 60 v bus in series with a step of starting resistance. An accelerating contactor then shorts the resistor and the motor accelerates to 150 rpm (base speed at 60 v).

At this point field-weakening increases the speed until the maximum at 60 v (300 rpm) is reached. This is equal to the speed at which the motor would run if connected to 120 v at full field strength. The motor, therefore, is disconnected and the field strengthened. Immediately, then, the motor is reconnected to the 120 v bus. This procedure continues until top running speed is reached.

THE EQUIPMENT

The accelerating torque demands a 75 hp, 240 vdc motor for each machine. A multiple-voltage bus powers the motor field at 240 v and the armature at 60/120/180/240 v, successively, as explained above. Incoming



MASTER BATTERY CONTROLLER
TIME FUNCTIONS

(1) Start cycle
(5) Start regenerative braking
(8) Start new cycle

INDIVIDUAL MACHINE CONTROLLER
CURRENT FUNCTIONS

(2) Accelerate to 600 RPM
(3) Start load fill
(4) Accelerate to top speed
(6) Start mechanical braking

LOAD FUNCTIONS

Load fill *
Load washed *
Top speed reached *
Zero speed reached *
Rheostat in "OFF" position *
(7) Start load discharge *

* *Alarm on failure to complete function*

Cycle diagram and associated controller functions. FIG. 3

line circuit breakers, main motor contactors, control relays (for voltage switching), and a large mill-type, multicircuit, motor-operated rheostat (for field weakening) control the acceleration. Motor-driven timers recycle the machines and the rheostat also serves as a timer for some steps in the cycle.

FEEDBACK POWER

Regenerative braking through field strengthening decelerates the motor prior to the mechanical braking period and feeds back power to the line. Thus, 75 per cent of the kinetic energy in the 75 hp driving motors is reclaimed and this supplies a portion of the power needed by other machines during their accelerating period. Note that part-time duty cycling and sequencing of the motors also reduces the power demand on the bus. The 3 hp, 30 rpm motors for reverse running are mechanically coupled only while discharging the batch. The attendant presses the controller start button to start the battery. The first machine begins accelerating—eighteen seconds later another machine starts —and so on until all machines are on the line. The first machine completes its cycle and restarts 144 seconds later, while the others continue through their various steps. The battery repeats its cycling under the influence of the master controller, unless some interlock or alarm on a machine indicates a malfunction.

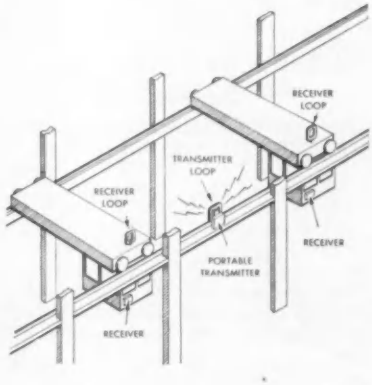
This complex system, briefly described, exemplifies an automatic control arrangement built up from standard industrial components. The photographs give good views of the control panels and sugar spinning centrifugals at National Sugar Refining Co., Long Island City, N. Y. Control equipment was furnished by Cutler-Hammer, Milwaukee, Wis.

Radio Loop Curbs Wayward Cranes

Disabled cranes (the machine kind) are a source of danger in a busy plant. Particularly when other cranes are in action on the same runway. Here is a simple radio-loop control that senses the positions of converging cranes and takes over before calamity can occur.

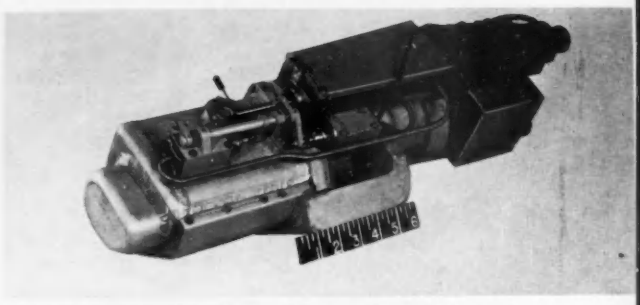
As the diagram shows, a portable radio transmitter is set up on the crane runway near the disabled unit, and receivers are installed in the two cabs. When the loop between transmitter and mobile receiver constricts—to an adjustable 20 ft or less—an output signal sounds the alarm or stops the oncomer.

Although this Femco, Inc. (Irwin, Pa.) system is intended primarily for safety, envisioned step-function and unique frequencies in each crane suggest a neat remote control idea.



Hydraulic Servo Actuator Has Low Standby Power

Here's a hydraulic system, originally designed for guided missile application, that combines mechanical features with friction-reducing electrical circuits.



One-package hydraulic actuator delivers ½ hp and features low-standby power, small size, and fast operation. FIG. 1

A. E. GOODWIN and D. A. R. MORRISON, General Electric Co.

Design of hydraulic servo systems for guided missiles demands special treatment. Factors to be considered include protection of the control surface actuator against extremes of temperature and vibration, and miniaturization of the unit into one package to satisfy installation requirements. When these conditions are met in a system that combines low-power consumption and no central oil reservoir or pipes, one actuator design approaches the ideal of missile builders.

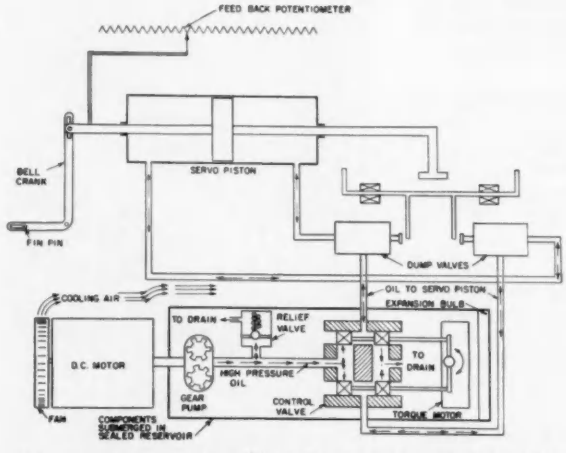
The fruit of thorough analysis of these requirements was a prototype actuator that operated reliably in the laboratory and on missile flights. There were four of these actuators to a missile, each delivering about ½ hp. They required no external cooling and were easily installed. The complete assembly is shown in Figure 1.

Low standby power was the most critical consideration. To obtain this, a calculated risk was taken in the control valve design. The valve underlap opening was increased until the standby pressure dropped to 100 psi, 1/15th of the maximum power. Subsequent testing proved the servo deadband was not affected by the larger opening.

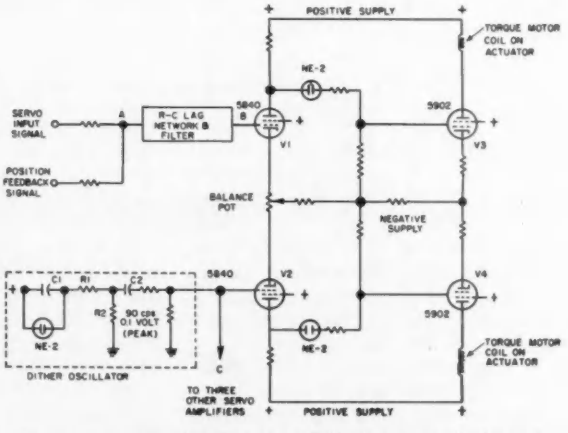
Heat transfer, even under this low-power condition, however, required a cooling system. A solution faithful to the concept of one-package design was a blower-pump motor arrangement with a shroud over the motor frame and hydraulic case-reservoir.

The actuator design resulted in the system schematically illustrated in Figure 2. A 28 vdc motor drives a small gear pump that generates the fluid pressure actuating the piston. The servo amplifier, upon receiving a signal, drives the torque motor and control valve to the proper position and regulates the pressure in the actuating piston. When the error signal reduces to zero, the torque motor stops and the control valve remains stationary to keep the actuator in the command position. Dump valves (hydraulic limit switches) are located at the extremes of travel. When the actuating piston reaches its limit, a push rod opens a dump valve, which ports oil back to the case reservoir.

The dc amplifier driving the torque motor is more or less standard (Figure 3). It contains, however, two circuits beneficial to the actuator operation. One is the lag network that filters out high-frequency noise and allows high static gain in the amplifier to reduce positioning errors under load; the other is the dither oscillator. Because of the valve's open center, neither frequency nor amplitude of oscillation is critical. Both merely impart a soft vibration to all moving parts. Vibration breaks up friction and greatly improves performance at low speeds.



Schematic representation of the final actuator design. Mechanical operation, in collaboration with the electric feedback potentiometer, gives accurate self-positioning of the piston. FIG. 2



Torque motor amplifier drives individual motor coils in push-pull arrangement. The dither oscillator reduces friction and improves performance at low missile speeds. The lag network allows high static gain, suppresses noise effects. FIG. 3

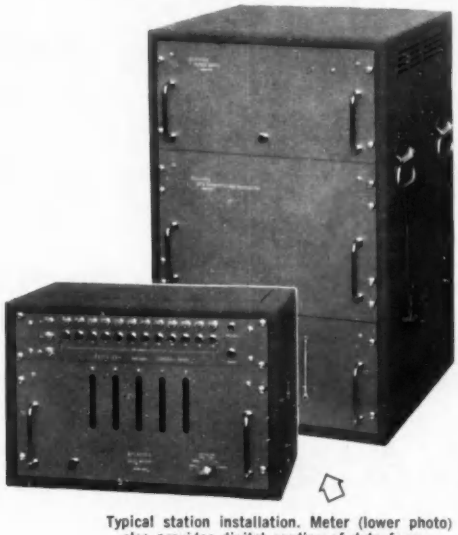
low cost telemetering

solves data communication problem for Gulf Interstate Gas Company

Two-wire line links 11 stations and Houston dispatcher's office in low-cost Automatic Telemetering System for Gulf Interstate Gas Company's 1160-mile gas pipeline.

Actual recording on standard teletypewriter paper; 8 of possible 12 channels used. Can also transmit flow, temperature or shaft position.

Station Code	Channel Code	Data	(Station suction and discharge pressures; r.p.m. of compressors, 1, 2, 3 and 4; test frequency)								
010	1	645			3	935					781
	01	245		2	03	244	04	240	06		
				645							
				245							
				02							



Typical station installation. Meter (lower photo) also provides digital reading of data from any 12 transducers in the station without transmission; may be set for automatic test scanning.

problem: How to link together 5 compressor stations, 6 gathering and distribution stations and the Houston dispatcher's office in a low cost system for telemetering pumping station data over distances of 1,000 miles.

solution: BERKELEY Automatic Data Transmitting System. Analog-to-digital transducers provide accurate measurement of pressure, temperature and r.p.m.; data is coded for transmission over A.T.&T. wire to remote teletypewriters. Houston dispatcher or any station operator can obtain up to 12 items of pumping station data in 45 seconds by dialing desired station's code number.

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3. **45-second transmission time for up to 12 readings from any station.**
4. **Low cost—less than $10,000 per station, including transducers.**
5. **Automatic check of all electronic circuits during each transmission.**
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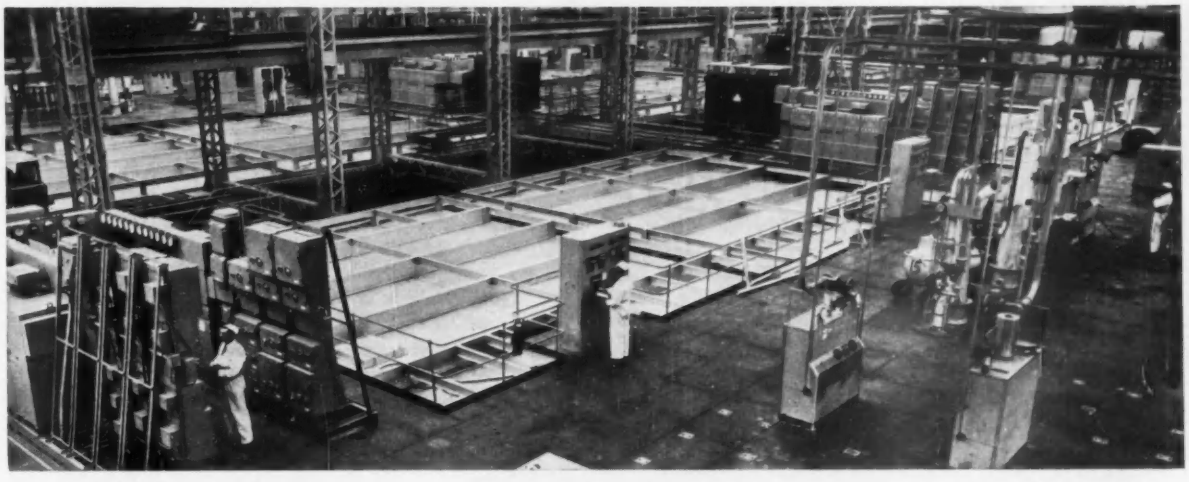


ON THE CONTROL DECK safely insulated from the active cells below, British engineers rely on stability and accuracy in sensing elements. FIG. 1

Sensors for Gaseous Diffusion

It takes a unique electro-magnetic transducer to safely hold critical gas pressures in Britain's huge U-235 extraction plant at Capenhurst.

Extracting U-235 from the heavier isotope, U-238, by gaseous diffusion is a ponderous, yet highly delicate process. A gaseous compound of uranium must be formed and caused to flow through a long series of membrane-separated cells. The lighter U-235 molecule—less than 1 per cent of the mixture—leaves each cell and is collected by tedious recirculation.

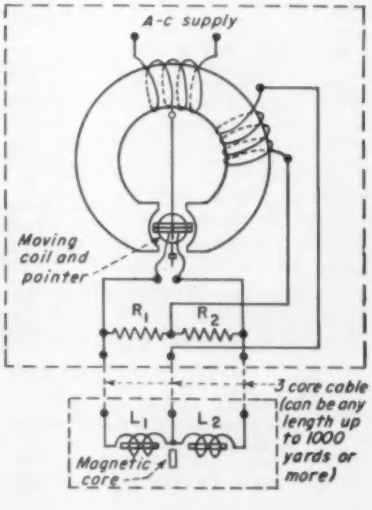
Three factors complicate the job of automatically controlling gaseous diffusion: 1) the natural toxicity of the material; 2) the critical pressures; 3) the gas itself—uranium hexafluoride, usually—which is highly corrosive, solidifies below 30 deg C, and reacts with substances to form solid contaminants.

Britain's sprawling Capenhurst gaseous diffusion process (Figure 1, the first official view released) has solved its critical remote measurements with a unique electro-magnetic transducer. As Figure 2 indicates, the lethal gas contacts a diaphragm stylus at the base of the transducer. The unit's magnetic core is sensitive to movements as small as 0.001 in.

The circuit diagram, Figure 3, reveals how the transducer forms a balanced bridge with the remote measuring instrument. The iron core in the transducer carries two coils. An ac supply provides the instrument's field and energizes the secondary winding in a bridge circuit formed by resistors R_1 and R_2 and coils L_1 and L_2.

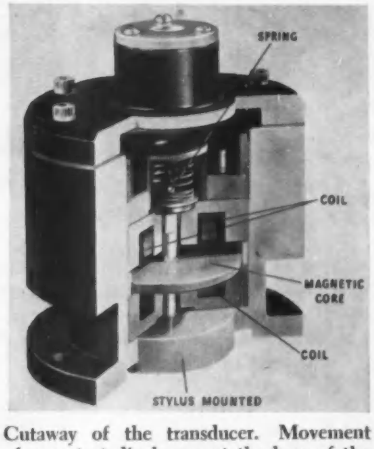
As the circuit indicates, bridge output voltage is substantially in phase with meter field flux, whereas induced voltage in the instrument's moving coil is in quadrature with field flux. Since coil-induced voltage is proportional to angular deflection with respect to flux, the flux variations in the transducer are balanced out by vector relationships of the bridge.

Since transducers used with uranium hexafluoride have to operate at 75 deg C, they are oven-calibrated at this temperature at the Capenhurst works. However, even the standard models of this simple pick-up—which is made by Salford Electrical Instruments, Ltd.—do not change by more than 1 per cent of the full scale reading over a range of 0 to 70 deg C.



Circuit diagram (right) shows moving pointer in the remote instrument angularly positioned by field flux developed by bridge formed by variable inductors in transducer and resistors. FIG. 3

. . . AND TRANDUCERS FOR THE PROCESS BELOW



Cutaway of the transducer. Movement of a contact diaphragm at the base of the shaft varies the magnetic flux proportionately. FIG. 2

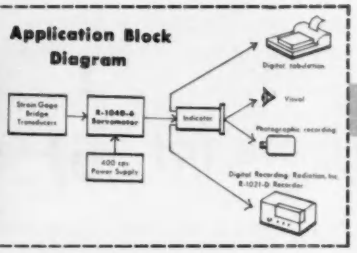
THE R-1040-6 Servometer*

A CONTROL FORCE MEASURING SYSTEM FOR INDUSTRY

that provides

1. Accurate measurements of better than ½%
2. Accurate measurement of pressure, force, acceleration, liquid flow, and position among others
3. High gain, with a frequency response of 15 C.P.S.
4. Excellent operation under adverse environmental conditions
5. Miniaturized and ruggedized construction
6. Direct operation from resistive type transducers

Application Block Diagram



The basic RADIATION, INC. Servometer consists of a High Gain Non-Linear Amplifier and Servometer. Reliable resistive type transducers are used to transmit information of a measured quantity to the amplifier. The signal is then amplified to a level of sufficient magnitude in order to drive the Servometer. The Servometer is designed for 110 volt, 350 to 450 cycle operation.

The versatility of the Servometer makes it adaptable to many industry functions that require measuring and/or monitoring applications. Is your application among these listed?

TYPICAL INDUSTRIAL APPLICATIONS

AIRCRAFT INDUSTRY

The Servometer will accurately measure forces applied to aileron, elevator and rudder controls for design and checkout purposes.

HEAVY INDUSTRY

With a load cell type transducer, the Servometer can be used to:

1. Weigh chemical tanks in a manufacturing process.

2. Weigh bucket loads on drag lines, both for quantitative analysis of total material removed and for overload protection to the operator.

3. Weighing ingredients in an aggregate mixing for cement plants, steel mills and feed plants.

AUTOMOBILE INDUSTRY

Employing the Servometer, accurate measurements of Power Steering Torque and Brake Pedal Forces may be obtained.

OIL INDUSTRY

Employing a resistive type pressure transducer, the Servometer will accurately measure liquid or gas pressures for monitoring purposes.

With a resistive type flow transducer, the Servometer will indicate a unit rate of liquid flow.

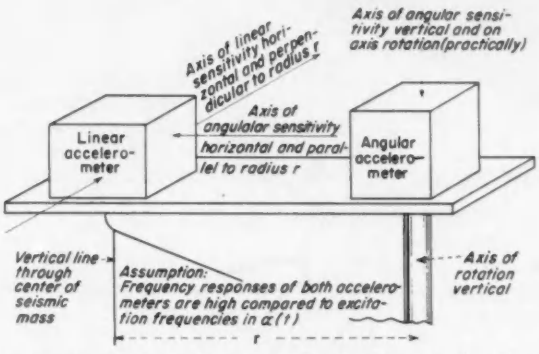
Servometers equipped with converters can be supplied to provide digitized outputs for Recording and Telemetering purposes as well as for control functions.

This equipment will be displayed at the Wescon Show August 24-26, 1955

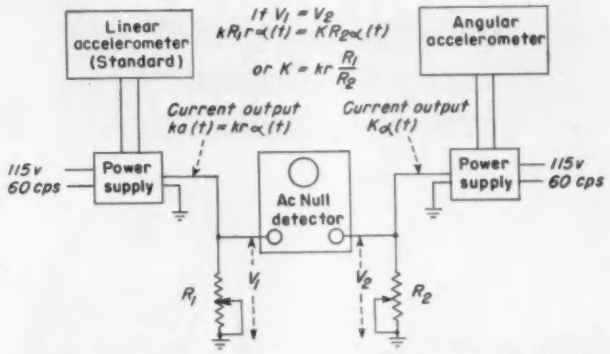
*Write for R-1040-6 **Servometer Bulletin** for details of variable applications

RADIATION, Inc.

Dept. 100 • P.O. Box #37 • Melbourne, Florida


Axis of linear sensitivity horizontal and perpendicular to radius r
Axis of angular sensitivity vertical and on axis rotation(practically)
Axis of angulalar sensitivity horizontal and parallel to radius r
Linear accelerometer
Angular accelerometer
Vertical line through center of seismic mass
Assumption: Frequency responses of both accelerometers are high compared to excitation frequencies in α(t)
Axis of rotation vertical
r

Calibrating angular accelerometer by the null method. FIG. 1



Electrical circuitry for accelerometer calibration by null. FIG. 2

Calibrate Angular Accelerometers Without Precise Accelerations

By this method the output of an angular accelerometer is nulled against a linear accelerometer whose output constant is accurately known. The two accelerometers are mechanically coupled in a simple geometry and the assembly given arbitrary accelerations by hand.

VICTOR B. COREY, Donner Scientific Co.

Precision standards of angular acceleration are not needed to calibrate angular accelerometers. They can be calibrated quickly, and in absolute terms, by a straightforward null balance method. With a linear accelerometer as a standard, an accuracy of about one per cent is produced, even at angular acceleration levels of a few radians per second squared.

The simple relationships between angular and linear parameters on a rotating radius arm, and certain physical characteristics of the accelerometers, permit this absolute calibration even with almost completely arbitrary input accelerations.

The linear accelerometer used as a standard is calibrated by measuring precisely its maximum positive and negative output during inversion under 1 g due to gravity. Its output current sensitivity constant (k milliamperes per ft per sec^2) can be calculated from the measured voltage drop across a known precision resistor.

THE CALIBRATION SETUP

Figure 1 illustrates the physical arrangement. When it is followed, the linear component of acceleration that excites the linear standard becomes directly proportional to the angular acceleration applied to the accelerometer being calibrated, and all other effects are negligible. These results are assured by the setup because:

▶ The axis of angular sensitivity in the angular accelerometer is vertical and as close to the axis of rotation as possible. Thus, the angular accelerometer senses the full value of angular acceleration, $\alpha(t)$, and effects of residual linear unbalance are minimized.

▶ The axis of linear sensitivity in the linear accelerometer is horizontal, so there is no output due to gravity. Also, it is perpendicular to both the radius of rotation, r, and the axis of rotation. Thus the full value of the tangential component, $a(t) = r\alpha(t)$, of angular acceleration is sensed by the linear accelerometer.

▶ Because the axis of angular sensitivity in the linear accelerometer lies in a horizontal plane parallel to radius r, this accelerometer generates no output due to its angular sensitivity.

With the physical arrangement in Figure 1 and the circuitry in Figure 2, any arbitrary angular acceleration about the vertical axis of rotation can calibrate the angular accelerometer, if its Fourier frequency components lie in the flat region of frequency response for both accelerometers.

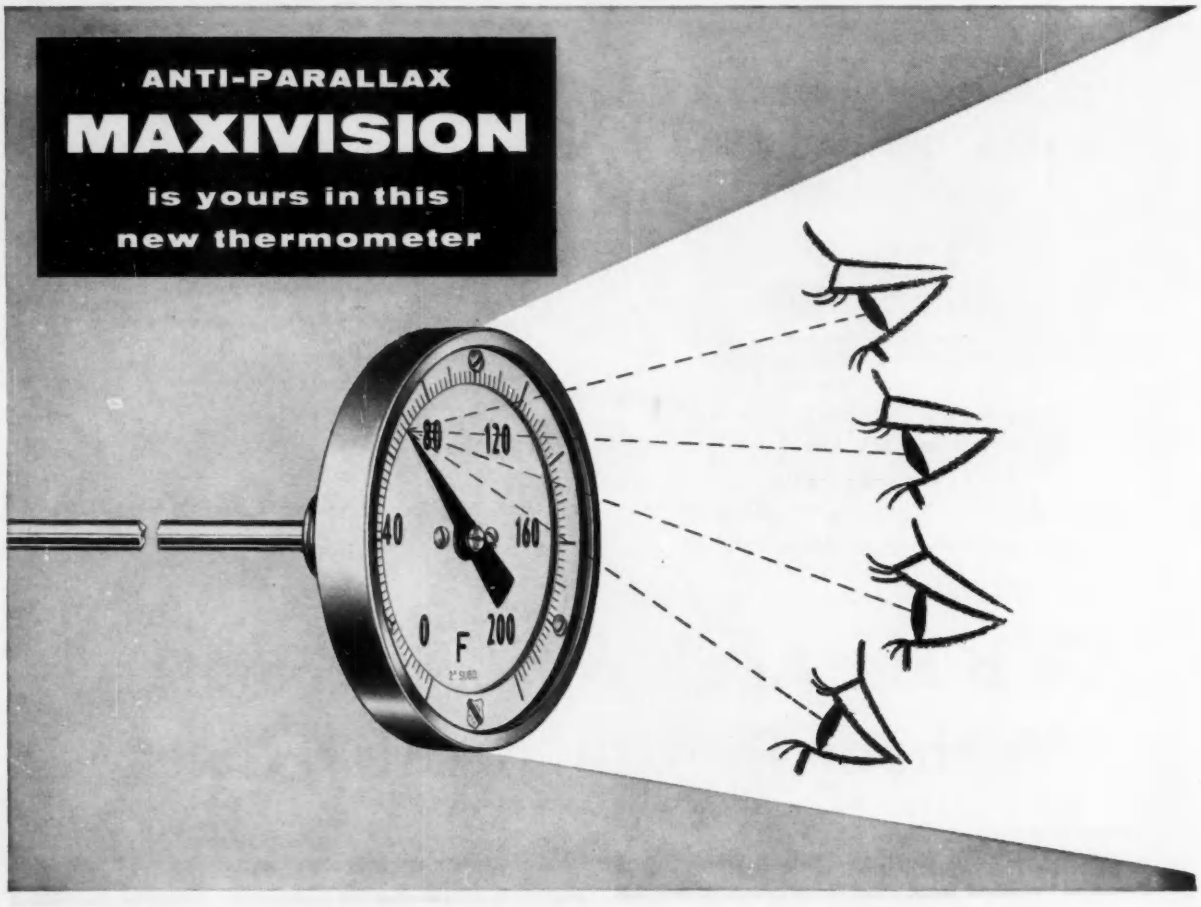
NULLING THE OUTPUTS

In Figure 2, the linear accelerometer generates a current $ka(t) = kr\alpha(t)$ milliamperes. This current flows through variable known resistance

ANTI-PARALLAX

MAXIVISION

is yours in this new thermometer



Now you can read temperatures *right at the process* with the same ease, accuracy and economy as pressure readings. The Anti-Parallax Maxivision Dial on this new all stainless steel American Bi-Metal Thermometer assures these important advantages. The large, easy-to-read black figures and graduations are carried on a raised ring set close to the glass, with pointer at the same level. Parallax error is practically eliminated.

With this new thermometer in service, field operators can eliminate frequent trips to the control house to observe process changes. Indoors or outdoors, this fine, all stainless steel American instrument is truly climate-proof. Because the case is only 3" in diameter, the thermometer fits where space is limited. Ample clearance behind the case makes installation easy and fast with a small wrench. Read the specification highlights, then get full details about this new high-accuracy American Bi-Metal Thermometer.

PHONE your Industrial Supply Distributor for prompt attention to your needs. He is always ready to help keep your production going by making fast delivery from local stocks.

SPECIFICATIONS

New AMERICAN ALL-STAINLESS STEEL BI-METAL THERMOMETER with ANTI-PARALLAX MAXIVISION DIAL

Dial: Exclusive anti-parallax Maxivision dial, with scale approximately 6" long. Pointer set at same level as scale.

Climate-Proof Case: All stainless steel. 3" diameter. Threaded bezel. Selected clear, extra-heavy cover glass. Heat-resistant gaskets between glass and case seal the thermometer against rain, frost, sand, dust, fumes—climate-proof.

Temperature Ranges: From minus 80° to plus 1000° F. Accuracy within 1% of range.

Low-Mass Bi-Metal Coil: Welded to stem plug. Accurately centered in stem. Non-freezing, non-corrosive silicone fluid on coil dampens vibration, accelerates heat transfer, speeds response; does not gum, resists capillary action.

Pointer: Index type. Easily accessible from front of dial for positive adjustment over entire range. Pointer shaft guided by friction-free bearings.

Stem: 18-8 stainless steel, mirror polished. All joints welded. Resists corrosion. Provides strong, rigid and tight closure against process pressures. Lengths: 2½" to 24".

Connection: Fixed, ½" N. P. T.

Separable Sockets: Available for use in closed systems or where measured medium is corrosive to the stainless steel stem. Fit over all standard stem lengths except 2½".

AMERICAN INDUSTRIAL INSTRUMENTS

A product of **MANNING, MAXWELL & MOORE, INC.** STRATFORD, CONNECTICUT

MAKERS OF 'ASHCROFT' GAUGES, 'AMERICAN-MICROSEN' INDUSTRIAL ELECTRONIC INSTRUMENTS, 'CONSOLIDATED' SAFETY AND RELIEF VALVES, *Stratford, Conn.* HANCOCK VALVES, *Watertown, Mass.* 'CONSOLIDATED' SAFETY RELIEF VALVES, *Tulsa, Oklahoma.* AIRCRAFT CONTROL PRODUCTS, *Danbury & Stratford, Conn. and Inglewood, Calif.* "SHAW-BOX" AND 'LOAD LIFTER' CRANES, 'BUDGIT' AND 'LOAD LIFTER' HOISTS AND OTHER LIFTING SPECIALTIES, *Muskegon, Mich.*

R_1. The angular accelerometer generates a current $K\alpha(t)$ milliamperes that flows through variable known resistance R_2. k is the known current sensitivity constant of the standard linear accelerometer. K, the sensitivity constant of the angular accelerometer, is to be found.

From the relationships in Figure 2,

$$V_1 = kR_1a(t) = kR_1r\alpha(t) \quad \text{across } R_1$$

and

$$V_2 = KR_2\alpha(t) \quad \text{across } R_2$$

A high-impedance ac voltmeter (like a cathode-ray oscilloscope) is used as a null detector to measure the algebraic difference between V_1 and V_2. Then, with arbitrary excitation $\alpha(t)$, the difference is reduced toward zero by proportioning R_1 and R_2. The sharpest null is obtained by setting R_1 to the highest feasible value and varying R_2 for minimum indication on the detector. At null:

$$V_1 = V_2$$

or

$$kR_1r\alpha(t) = KR_2\alpha(t)$$

Thus

$$K = krR_1/R_2$$

ACCURACY OF THE METHOD

Because of the simplicity of the measurement and the constant source of excitation (gravity), the linear standard accelerometer can be calibrated easily to an error of only 0.1 per cent. R_1 and R_2 can be precision multi-turn potentiometers with linearities of 0.1 per cent or better. Thus, errors due to lack of precision in the resistances should be less than 0.5 and can be as low as 0.1 per cent.

Error is primarily due to lack of sharpness in the null, which prevents precise determination of the ratio R_1/R_2. This error, a function of the relative phase shift in the output signals of the two instruments, is aggravated by frequency components in the exciting acceleration that are high compared to the frequency responses of the accelerometers. Experience shows that null resolution errors should not exceed one per cent.

The radius r can be measured easily to within 0.025 in. Because r itself is approximately 26 in., error in this measurement can cause less than 0.1 per cent error in K.

Overall error thus lies between one and two per cent for routine calibrations, and limiting error should be less than one per cent.

• • •

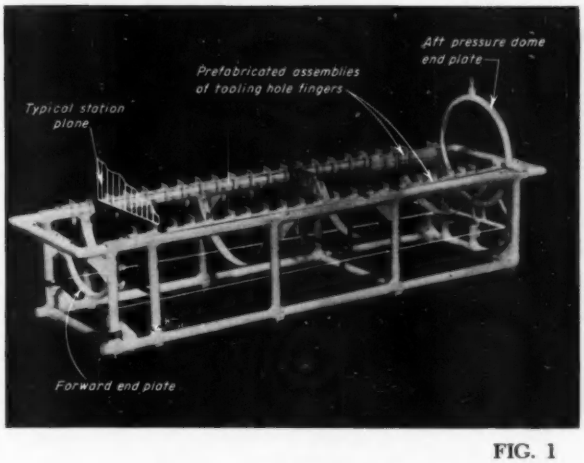

Aft pressure dome end plate
Prefabricated assemblies of tooling hole fingers
Typical station plane
Forward end plate

FIG. 1

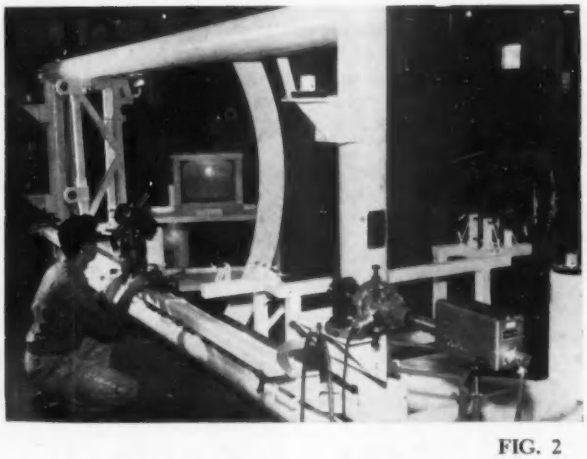


FIG. 2

TV SHARPENS MEASUREMENTS

Precision aircraft assembly jigs become 300 times more accurate with a closed-circuit television system that transfers a sighting image from the eyepiece of a telescope to the screen of a 19-in. television set. The jig in Figure 1, for the aft lower half fuselage of a DC7C, consists of "cradles" of steel pipe on which tooling fingers position parts of the assemblies.

An optical square, which fixes points at right angles to the line of sight of the telescope, guides construction of an assembly jig. A light beam projects a target, etched on the focal plane of the telescope, to a mirror on the optical square. When the target is reflected exactly on the cross-hairs of the telescope, as seen on the TV screen, the optical square is adjusted to exactly 90 deg to the line of sight (Figure 2).

This new jig-building technique, developed by Douglas Aircraft Co., not only increases jig accuracy, but speeds construction. One man does the alignment rather than two, and eyestrain is eliminated. Furthermore, it allows simultaneous observation by the jig builder and the tool inspector.

NEW PRODUCTS

LISTING IN GROUPS

1- 3 Three Data Handlers
4- 9 Measuring Advances
10-16 Digital Devices
17-21 Flow Controllers
22-31 Switches and Timers
32-37 Some New Transducers

DATA HANDLING:

1- COLLECTION

Packaged system herds measurements from 28 transducers onto a 1¼ in. tape.

As pilotless aircraft and guided missiles surge beyond range of effective telemetering, the need to collect flight performance data grows more acute. One solution to the dilemma is Consolidated Engineering's *Datatape*—a data collecting package designed to operate under unearthly conditions and bring the needed info back all neatly stored on magnetic tape.

Modular elements of the system include a recorder, amplifiers and modulators, a calibrator, a time-code generator, and remote control power supply. The recorder-amplifier package is above, left. Its input plugs are for 24 data channels and 4 auxiliary channels. The opened view of the recorder, above, right, shows its tape reels and transport assembly. Tape capacity is 43 min. The tape stores 28 tracks of information at 10 in. per sec. Thinner tape will extend the play time. An ingenious design outfits this system for its rugged chore. The recorder spots its own malfunction—mechanical or electronic balks are detected by a monitor head and warning flashed to the remote control station. Tape transport is rigid cast and shock mounted to avoid warp problems and isolate the capstan assembly from vibration. Some performance figures: lf flutter at 0.1 per cent peak-to-peak or less; hf flutter (above 100 cps) from 0.2 to 0.35 per cent; recording error less than 1 per cent with pulse-duration modulation less than 3 per cent with wide band fm.

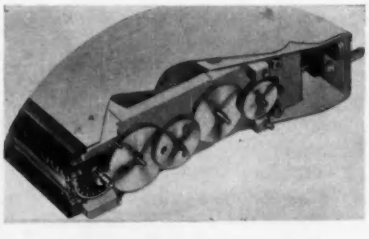
At right is the *Datatape* recorder set up in rack mounting. The tape-stored signals can be recovered in digital form using the Consolidated *millisadic* analog-to-digital conversion system. *Consolidated Engineering Corp., 300 North Sierra Madre Villa, Pasadena 15, Calif.*

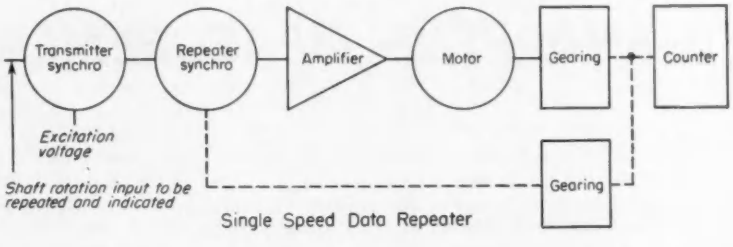
Circle No. 1 on reply card

DATA HANDLING:

2. CONVERSION

Analog-to-digital converters meld precision with plug-in practicability.





Single Speed Data Repeater

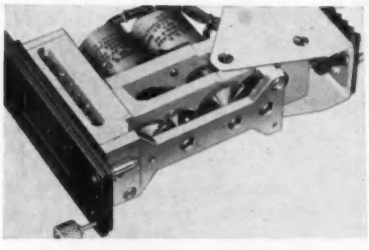
Converting information from a rotating shaft or voltage source into accurate digits is a precise job that has challenged control field inventiveness during the past year or two. Now a new entry launches a formidable name —General Motors—into the highly-charged analog-to-digital field.

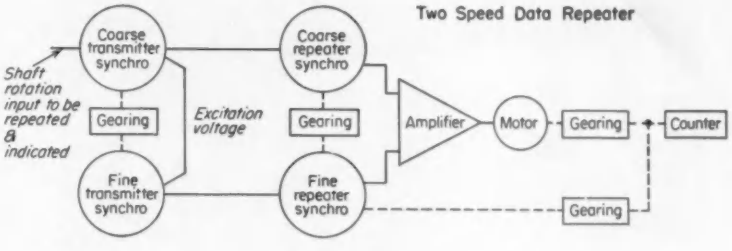
GM's AC Spark Plug Div. sired this new line, which it calls *AC Data Repeaters*. Three basic types are offered: a single-speed synchro to digitize shaft rotation; a two-speed synchro for more accuracy in shaft conversion; and a potentiometer type to

convert voltage to digits. The units are equipped with either 26 or 115 v motors, which are able to rev up to 3,400 or 6,800 counts per min respectively. Counters with from two to seven wheels can display white-on-black numbers in a plastic edge-lighted window. A shutter-style double counter is also available for plus or minus counting from zero. The units all have plug-in connectors for front of panel mounting.

The single speed synchro shown at the bottom of the opposite page has gear ratios from 50:1, displaying 50 counts, to 100:1, displaying 1,000 counts. Shown below (left) on this page is the two-speed synchro with gear ratios ranging from 50:1 to 3,000:1, the latter displaying 30,000 counts. The potentiometer unit (not shown) offers gear ratios from 0.25:1, displaying 25 counts, to 20:1, displaying 2,000 counts. All units occupy approximately 3 in. by 2 in. panel space and weigh about 1 lb. Reading resolution for all is within 0.2 digits, no matter what the ratio or counting range are. *AC Spark Plug Div., General Motors Corp., 1925 E. Kenilworth Avenue, Milwaukee 2, Wis.*

Circle No. 2 on reply card

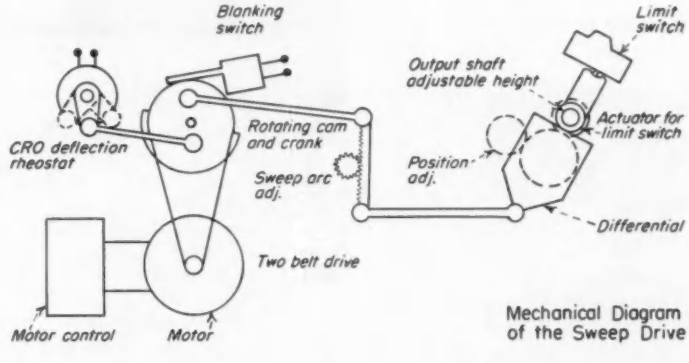




DATA HANDLING:

3 - DISPLAY

Sweep drive fans out continuous data by mechanically positioning an oscillator.



Mechanical Diagram of the Sweep Drive

Sweep techniques that display data as continuous functions of an independent variable are an invaluable time saver for the control engineer. The most familiar use involves sweeping an oscillator to display amplitude-frequency characteristics. Many mechanical or electronic integral sweep oscillators are already available for the job. But here is a new system—a mechanical drive and associated power supply—that can be attached to any oscillator to fit it for a specific measuring chore.

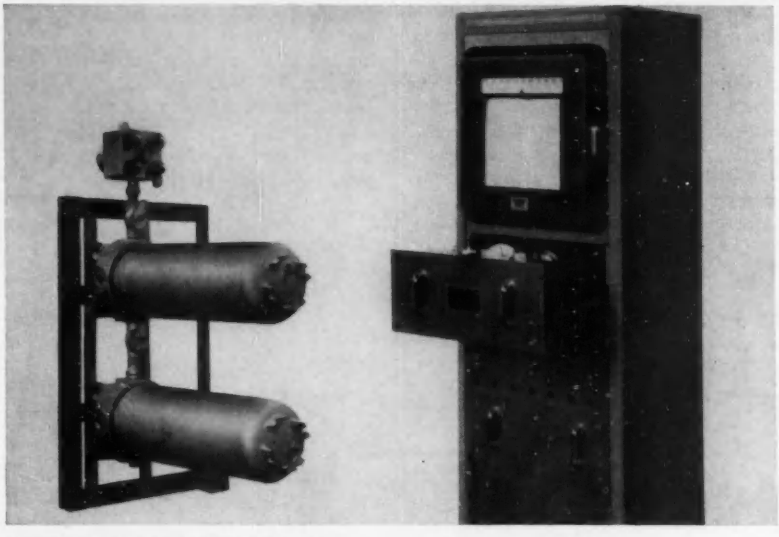
The photograph and diagram show elements of the system and how it works. In the foreground of the photograph is the Type 1750-A drive. It is mechanically linked to the shaft of the oscillator at its rear. Two controls adjust the sweep arc and its center position while the drive shaft is in motion. At the left in the rear is the Type 1236-A amplitude-regulating power supply that maintains constant oscillator output as the frequency is swept.

As the diagram shows, the sweep drive is powered by a 5,000 rpm universal motor, and a crank driven through two belts provides the necessary speed reduction. Operated from the crank is a rack which is positioned by the sweep arc control knob. A connecting rod and differential links the rack to the output shaft. The arrangement is adjustable over a speed range of from ½ to 5 cycles per sec. The sweep arc is independently adjustable from 30 to 300 deg.

Aside from oscillator sweeping, the drive also offers a sweeping voltage, proportional to shaft angle, which can be applied to the horizontal deflection plates of a cathode-ray oscilloscope. Hence a circuit under test could supply the vertical deflection voltage and the frequency characteristics of a network could be displayed on the 'scope. As a matter of fact, the set-up could be used in the sweep display of any quantity that can be converted to an electrical voltage. *General Radio Co., 275 Massachusetts Avenue, Cambridge 39, Mass.*

Circle No. 3 on reply card

ADVANCES IN MEASUREMENT



INFRARED ANALYZERS adjust to processing problem.

Four new Tri-Non infrared analyzers for continuous analytical control of chemical process gas streams vary in function to meet requirements. They range from highly sensitivity models for the most complex processing problem to simple units for monitoring relatively simple process streams. They can be explosion-proofed and supplied with recording and remote-location equipment. Prices extend from $2,800 to $5,450. *Perkin-Elmer Corp., Norwalk, Conn.*

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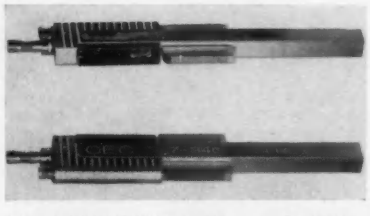
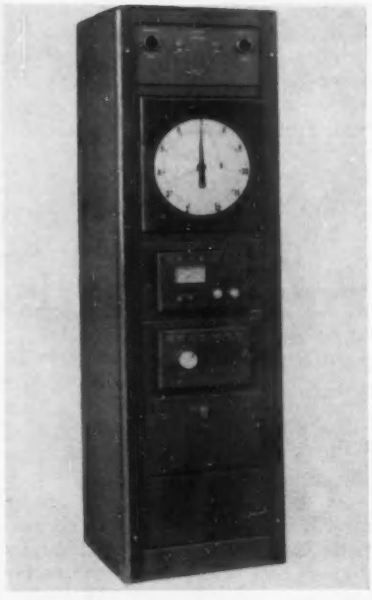


GALVANOMETERS reach 200 cps without amplification.

Flat frequency response provided by 7-300 series galvanometers reaches 200 cps without signal amplification between transducer and recording.

Several of the High-Performance family of galvanometers can replace present style units without circuit changes. Typical application is direct-connected measurement of unbalance current with common strain gages and other resistance pick-ups. Frequency response differs for various units. It ranges from 0-90 cps to 0-200 cps. Undamped sensitivity at 11.5 in. optical arm varies from 10.2 to 34.7 microamp per in. deflection. *Consolidated Engineering Corp., 300 North Sierra, Pasadena 15, Calif.*

Circle No. 5 on reply card



YOU CAN PLUG IN this one-package pH control system.

Here is a complete, single-package system for single or multiple channel monitoring, recording, or controlling of any pH process application. Basic components are assembled in accordance with the user's requirements and furnished mounted, wired, and piped ready for plug-in installation. Combinations of equipment provide functions ranging from simple pH meter and alarm circuits to elaborate multiple-channel monitor recorder-alarm control systems. *Beckman Instruments, Inc., Beckman Div., Fullerton 1, Calif.*

Circle No. 6 on reply card

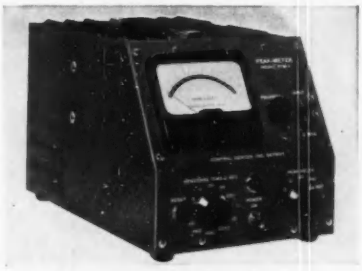
FRONT PANEL controls recording oscillograph

Versatile operation of these Series 700 recording oscillographs are a credit to their design. Simplified internal adjustment and controls on the front surface facilitate information gathering, while daylight record magazine loading and instantaneous selection of recording speeds minimize set-up time.

Model 708C has a maximum of 32 channels and handles record widths to 8 in.; Model 712C handles up to 60 channels at record widths to 12 in. Both models use recording films or papers up to 12 in. wide. Four speeds can be selected instantly without interrupting the recording cycle; in addition, other speeds can be obtained through the manual changing of gears. The complete range is from ½ to 144 in. per sec in 24 separate speeds.

Features include grouping of record speed and record length selectors and front access to record magazine, galvanometer area, and damping panel. *Minneapolis-Honeywell Regulator Co., Herland Div., Denver, Colo.*

Circle No. 7 on reply card



PEAK READING voltmeter shrugs at wave shape.

This ballistic voltmeter handles pulses that are too fast for conventional meters. It combines response speeds as low as two microsec with a full scale error not exceeding two per cent. Its range extends from 0.1 to 300 v, it responds to peaks regardless of wave shapes, and it holds the reading until the reset button is pushed. Although primarily intended for measurement of crest amplitude of single pulses, the PTM-7 Peak-Meter is more effective for repetitive pulses than its predecessors. *Control Devices, Inc., 8299 East 9 Mile Road, Van Dyke, Mich.*

Circle No. 8 on reply card

CONSOLE OSCILLOSCOPE has screen tilted for precision.

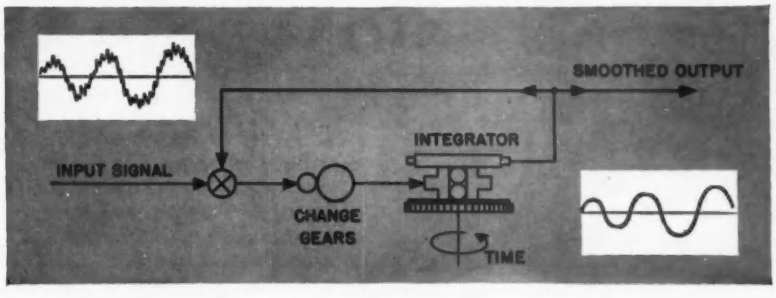
Particularly useful in production testing is this console oscilloscope with 17 in. rectangular tube and work shelf at convenient desk height. The tube and controls tilt for maximum viewing-ease and operation. Modernized console construction includes silver and charcoal-gray finish over steel, ventilated cabinet, and space for storage and additional circuitry. Overall dimensions: 42⅞ in. high, 23⅛ in. wide, and 37 in. deep. *Electromec, Inc. 3200 North San Fernando Boulevard, Burbank, Calif.*

Circle No. 9 on reply card

SINCE 1915 LEADERS IN AUTOMATIC CONTROL

Smoothing Signal Noise with the DBR* Integrator

Confronted with the well-known problem of random fluctuations called "noise," Ford engineers have employed the earliest and best-known Ford component – the disk integrator. Used in Ford analogue computers, the disk integrator smoothes random fluctuations due to extraneous influences and obtains an average of the received signal. Thus, a device originally designed by Ford for integration is successfully used as a mechanical counterpart of the RC Filter.



The Ford circuit operates on the premise that the older the data the less important it is. Therefore, data smoothed must be weighted in proportion to its age, so that the weight assigned to it decreases exponentially with time. The output of the circuit then represents the summation of this weighted data and tends to ignore random noises of short time duration.

As shown in the drawing, the incoming signal (with noise superimposed) is the input to the differential. As long as the integrator output (the roller) rotates at the *same rate* as the incoming signal, the differential output (error signal) is stationary and the integrator carriage remains stationary. But any change in the incoming signal produces changes in the *error signal* which tends to displace the integrator carriage and thus restore the system to equilibrium.

This reaction, however, is not instantaneous. It occurs after a certain time-lag which may be adjusted by the gear ratio. If the signal is of brief, random nature, the time-lag of the integrator will prevent its acting on the system. On the other hand, a permanent change in the signal will displace the carriage and change the output of the system.

This use of the Ford disk integrator as a noise smoother exemplifies the flexibility and adaptability of Ford components and ideas.

*Disk, Balls and Roller Integrator

68

FORD INSTRUMENT COMPANY
DIVISION OF SPERRY RAND CORPORATION
31-10 Thomson Avenue, Long Island City 1, N. Y.

ENGINEERS
of unusual abilities can find a future at FORD INSTRUMENT COMPANY. Write for information.

DIGITAL DEVICES

PRINTED DIGITS record shaft position in this readout.

The manufacturer's photo of a readout system that couples his "Digitizer" and the Model 1900 Clary Printer does not, unfortunately, contain the box that makes it all possible. The box contains two relays, a transformer, and two selenium rectifiers and plugs into the back of the modified printer. The system can divide a revolution into 10, 40, or 100 parts Additional information can be entered to identify readings. Another model of the printer will add the time of day. The input shaft must be stopped during readout. *Coleman Engineering Co., 6040 W. Jefferson Boulevard, Los Angeles 16, Calif.*

Circle No. 10 on reply card

MULTI-TRACK HEADS wear plastic casts.

New heads, designed specifically for data recording applications, promise extreme flexibility in track spacing, and track and gap width without quality loss. The heads are cast in plastic and mounted in metal housings to weather shock, vibration, temperature, and humidity. From 7 to 21 tracks per in. are available in widths up to 2 in. Gaps can be as small as 0.00015 in. *Davies Laboratories, Inc., 4705 Queensbury Road, Riverdale, Md.*

Circle No. 12 on reply card

QUICK STARTS, STOPS for auxiliary mag-tape memory.

For fast starting and stopping on the order of 4 millisec, the "datacorder" transports magnetic tape from basket to basket. Only the tape suspended from the capstan must be accelerated. Two counter-rotating capstans are always running at full speed. Two rubber-tired pinch rolls, always in light contact with the undercut capstans, are moved by solenoids about 0.002 in. to drive the tape. The reel on top is for storing tape when it is not in use. Basket storing is not recommended. The Datacorder takes tape up to 2 in., heads up to 44 channels. *Brush Electronics Co., 3405 Perkins Avenue, Cleveland 14, Ohio.*

Circle No. 13 on reply card

MINIATURE delay lines can adapt easily.

These "sticks" are available with bandwidths to 30 mc, impedances from 200 to 5,000 ohms, and delays up to 4 microsec in a 6-in. length. They are distributed constant lines. Series "FD" lines are ⅛ in. in. diam. Performance and delay determine their lengths. They are suggested by the manufacturer as components in computers, color TV, oscilloscopes, etc. *Control Electronics Co., Inc., 1925 New York Avenue, Huntington Station, N. Y.*

Circle No. 11 on reply card

FLEXIBLE CARD punch coupler saves steps, time.

This new "Intercoupler" ties National Cash Register series 3100 or 3200 accounting machines directly to IBM card punches (Model 016, 103, 031, 024, 026, and 526) or to 5 to 8 channel Commercial Controls Model 2 tape perforators. It produces cards or tape automatically while the operator is posting records. When the punch is unplugged from the coupler, both machines operate normally. No permanent modifications to the IBM punch are necessary. A safety interlock prevents operation of the posting machine if the punch runs out of cards or tape. *Systematics, Inc., 105 Lyndon Drive, Hermosa Beach, Calif.*

Circle No. 14 on reply card

SHORT PULSES stretched to constant width.

This is a miniature pulse expanding network that generates 5 microsec pulses from input pulses 0.05 to 2 microsec wide. Output amplitude can follow input amplitude variations or vary with the input pulse duration. With slight additional circuitry, output amplitude is constant with varying input pulse width. Size 1 by 1 by 1½ in.; operating temperature range minus 70 to plus 135 deg C. *The Gudeman Co., 2661 South Myrtle Avenue, Monrovia, Calif.*

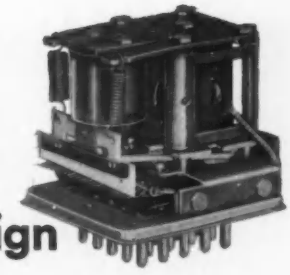
Circle No. 15 on reply card

SIMPLE IMPACT counter handles metal, non-metal.

This impact counter gets its signal from an accelerometer. It can count metallic or non-metallic parts of any weight or size at rates up to 250 per min. A six-digit reset counter and a neon lamp give count indication. Options include external reset and preset counting to produce a signal after a given number of counts. *Control Devices, Inc., 8299 East 9 Mile Road, Van Dyke, Mich.*

Circle No. 16 on reply card

Why REGOHM Regulators are preferred by design engineers for these applications



Selenium Rectifier Power Supplies

REGOHM regulates voltage of this selenium rectifier power supply used in testing aircraft equipment. Despite widely varying input voltage of the equipment, stability problems are solved by REGOHM's built-in, thoroughly reliable dashpot. No anti-hunt networks are required. System design is simplified.

Aircraft Inverters

REGOHM controls the frequency of the aircraft inverter that powers the B-47's automatic fire control system. It withstands severe shock, vibration, temperature ranges from −65°C to +71°C and 50,000 foot altitudes. Its performance cannot be matched by any equipment of comparable size, weight or cost.

Motor Generator Sets

REGOHM means close-tolerance voltage control on motor generator sets up to 40KW that power machine tools. The regulator's fast speed of response saves wear and tear when tools are started and stopped. REGOHM's long life is measured in years. Its plug-in feature simplifies replacement by unskilled personnel.

Infrared Spectrometers

REGOHM controls current to assure constant radiation from infrared source, enhancing the accuracy of this infrared spectrometer. The regulator's characteristics, compactness and reliability simplify system design. It replaces heavier, more expensive and complex, but less accurate, equipment.

Check this list:

- ☐ Battery Chargers
- ☐ Airborne Equipment
- ☐ Portable and Stationary Generators
- ☐ Marine Radar
- ☐ Underwater Sound Systems
- ☐ Telephone Central Station Equipment
- ☐ Railroad Signal Systems
- ☐ Refrigeration Equipment
- ☐ Filament Regulation
- ☐ Computers
- ☐ Airport Lighting Systems
- ☐ Inverters
- ☐ Railroad Car Lighting Systems
- ☐ Locomotive Braking Systems
- ☐ Wire and Radio Communication Systems
- ☐ Air Navigational Systems
- ☐ Guided Missiles
- ☐ Oil Field Exploration Systems
- ☐ Signal and Alarm Systems
- ☐ Instrumentation Systems
- ☐ Magnetic Clutches
- ☐ Tension Control Equipment
- ☐ Saturable Reactors

If you find your equipment or system listed, or have a problem in other fields, contact Electric Regulator Corporation, 120 Pearl Street, Norwalk, Conn. Our engineers will help you design required circuitry... recommend the proper REGOHM type... calculate the resistor network... suggest design modifications for optimum performance... analyze final designs... assist in testing pre-production models... service your requirements. Write us today.

REGOHM

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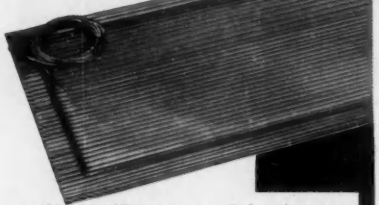
Norwalk, Connecticut Temple 8-4311

RECORA Switchmat



. . . thin, mat-like pressure switches that close circuits whenever pressure is applied to any point in their area; open circuits when pressure is released. Widely used as "area switches" on floors and platforms for automatic door openers, alarm systems, traffic controls etc. Used around machinery for foot switches, safety stations and emergency cut-outs. Available in any size, shape or quantity, for integral, built-in parts of mechanisms, devices and systems.

Operate at pressures from few ounces up, on low voltage, directly connected or through relays. Hermetically sealed between sheets of wear, acid and oil resistant vinyl plastic. Standard units, or to your specifications. Technical service supplied; just send us your switch problems.

Catalog Sheet C856 describing Recora Switches and control accessories sent upon request.

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For Mark 7 and 8 Servo Motors

MAGNETIC SERVO AMPLIFIER

- Response time of one cycle
- Temp. range −55°C to +85°C
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- Hermetically sealed reactor unit only 2½" high and 2¼" diam., weighs less than 12 oz.

The R40G10W1 can be supplied either as illustrated or with a built-in magnetic, transistor, or vacuum tube preamplifier. The moisture and fungus proofed rectifier is supplied for external mounting. This economical and rugged unit is ideal for integration with servo systems requiring Mark 7 or 8 motors. Write for details.

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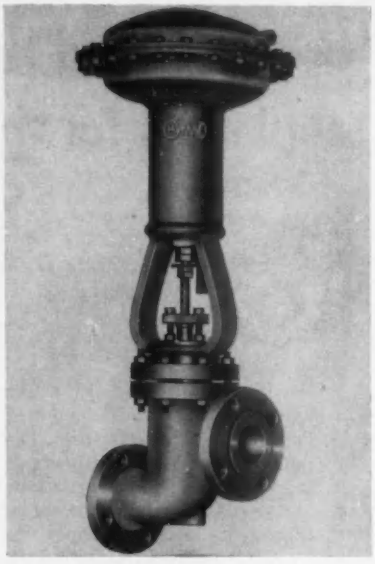
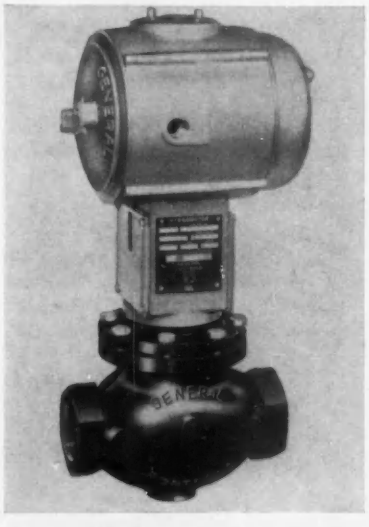
FOR FLOW CONTROL



TRIM DESIGN saves space and costly alloys.

A conventional 2 in. globe valve with a bellows seal to isolate dangerous fluids usually occupies 40 in. from top to bottom. This new line, called *Ultravalve*, will handle the same chore in 28¾ in. space. And in doing so it cuts down on the costly alloys needed for hazardous jobs. The unit shown is an offset body type which self-drains toxic or corrosive fluids. Its bellows seal is welded to the stem. The seal's location in the neck of the body is the big reason why size is reduced. The valve also comes in angle or in-line body shapes and its size ranges from ½ in. to 6 in. *Hammel-Dahl Company, 175 Post Road, Providence 5, R. I.*

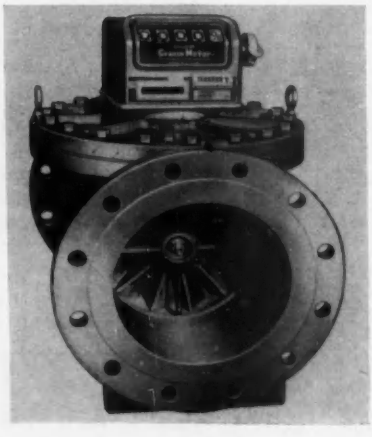
Circle No. 17 on reply card



ONLY 4 WATTS hold this electro-hydraulic unit open.

Though especially designed for oil lease requirements, this powerful line of electro-hydraulic valves should interest other industrial users too. Only 80 volt amps are required to drive it open in 12 to 23 sec. And only 9 volt amp (approximately 4 watts) keep it in the open position. A heavy duty return spring closes the valve when it is deenergized. The unit comes in 1 to 3 in. sizes and will handle from 50 to 300 psi. *General Controls Co., 801 Allen Avenue, Glendale, Calif.*

Circle No. 18 on reply card



DUAL ROTORS churn 22,000 gpm through this meter.

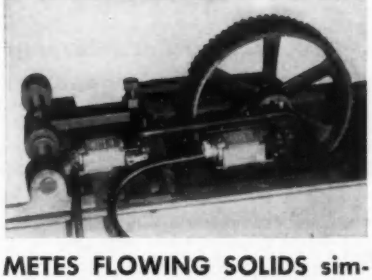
The maker declares this is the world's highest capacity petroleum meter. This is hard to dispute since the unit will handle from 3,000 up to 22,000 gallons per minute. Two counter-rotating dynamically balanced rotors are responsible for the prodigious capacity. Liquid deflects from the first to the second, and enters liquid already in the second at right angles to the face of its blades. The result: a turbine-like power and sealer giving required accuracy down to 20 per cent of capacity. *Granberg Corp., Oakland, Calif.*

Circle No. 19 on reply card

SAFETY SHUT-OFF flicks quickly into service again.

The maker has equipped its regular line of diaphragm control valves with this delatching trip mechanism. Here's the idea: if the valve is moved to a safe open or closed position due to some failure in the system it can be thrown into service again by manually setting its latching lever. The mechanism should see excellent use as a pressure-loss pipeline shut-off, or as a safety shut-off on fuel lines. *Black, Sivalls and Bryson, Inc., 7500 East 12th Street, Kansas City, Mo.*

Circle No. 20 on reply card



METES FLOWING SOLIDS simply by riding up and down.

The iron wheel in the picture is riding freely on solid material passing along a conveyor belt. A cam on the end of its shaft actuates a relay switch that shoots pulses to a remote counter calibrated in weight of the material being conveyed. If the material on the conveyor decreases, the wheel sags down and a contact is made which stops the conveyor. The maker of the Volumeter does not suggest it but it may also be possible to register wheel displacement and correlate this with variations in conveyed quantity. *Elliott Co., Box 437, Newark, N. J.*

Circle No. 21 on reply card

NOW

REMOTE CONTROL

of your entire plant operation

...at your fingertips!

NEW

TALLER & COOPER

TELEMETERING SYSTEM

supervises multiple functions with only 2 wires!

NEVER BEFORE such a simplified method of telemetering! Over a single pair of wires, multiple control of great numbers of functions is possible. The unit is rugged, compact, economical to run—an ultra reliable machine that affords complete plant control with the push of a button or switch.

Write for detailed specifications.

This new telemetering system supervises the control of 10, 16, 20 or 32 plant operations instantaneously!

Combinations of these units can increase control to 100, 250 or even more functions, if needed.

Push button or switch control operates valves, pumps, motors, switches, fans, signals, etc.

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- Wind Tunnel Instrumentation
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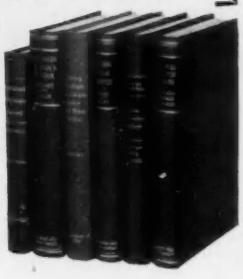
Basic facts, data, and information you need for more effective CONTROL WORK



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Look to this practical Library for vital data on control circuits . . . essential information on automatic feedback control systems . . . and the mathematical theory of servos.

In addition, you find outlined the mathematical and physical mechanisms developed for use in automatic computation, important facts on d-c analog computers, and help on observing analogous systems.

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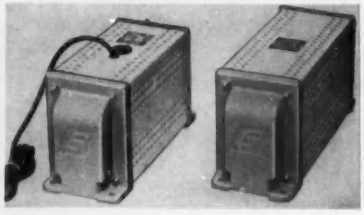
CON-8

NEW PRODUCTS

MAGNETICS IN CONTROL



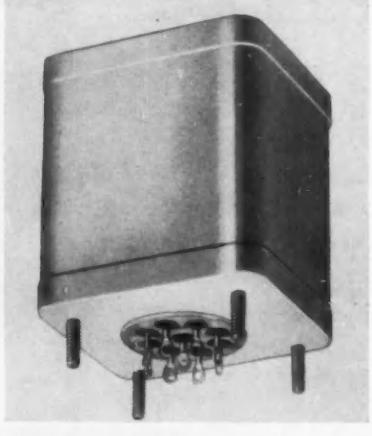
MAGNETIC VOLTAGE regulators for line stabilization.

Two higher capacity, 250 and 500 va, magnetic voltage regulators have been added to this manufacturer's line of 15, 30, 60, and 120 va units. *Sorenson & Co., 375 Fairfield Avenue, Stamford, Conn.*

Characteristics:

Input voltage range	95-130 vac, 1 ph, 60 cps
Output	115 vac, 1 ph
Regulation	plus or minus 0.5 per cent against line changes, zero to full load
Time constant	2 to 6 cycles

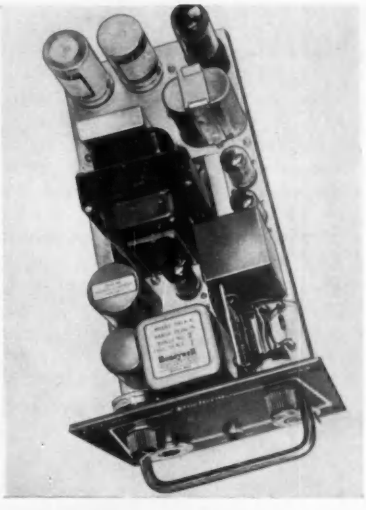
Circle No. 22 on reply card



HERE'S A NEW magnetic amplifier line.

The model shown is a 400 cps, 115 v, two-stage amplifier with a power gain of 2 million and a response time of 1 sec. Input impedance is 200 ohms; load impedance, 3,000 ohms. It is one of a new line of toroidally wound, heremtically sealed, or plastic encapsulated magnetic amplifiers. Wide ranges of impedance, power gain, and response time are offered at common supply frequencies. Bulletin MA tells more. *Hycor Co., Inc., 11423 Vanowen Street, North Hollywood, Calif.*

Circle No. 23 on reply card



LINEAR DC amplifier uses magnetic converter for modulator.

A second-harmonic magnetic converter replaces the usual chopper as the input modulator in this new dc amplifier. The results: linear output, high sensitivity, and low noise level. A plug-in range unit makes gain and bandwidth easily changeable. Input terminals isolated from amplifier ground are available optionally. *Doelcam, Soldiers Field Rd., Boston 35, Mass.*

Characteristics:

Input	standard plug-in ranges form 0.1 mv to 100 mv
Gain	Up to 10^6
Output	Plus or minus 10 v into 1,500 ohm load full scale, 25 v max
Zero drift	Less than one per cent of full scale on any range above 1 millivolt
Noise level	Less than ½ per cent of full scale

Linearity .... 0.1 to 5 per cent of full scale depending on range and frequency response.

Frequency response... Up to 80 cps depending on range used.

Circle No. **24** on reply card

MAGNETIC AMPLIFIER has 1-cycle response at 400 cps.

The stabilization problems that usually accompany use of magnetic amplifiers in control systems are reduced by the fast respose of these new units. They will deliver up to 15w, 57v to the control phase of a 400-cps servo motor. They deliver reversible output phase for reversible ac or dc input. *Polytechnic Research & Development Co., Inc., 202 Tillary Street, Brooklyn 1, N. Y.*

Characteristics:

Supply ..... 115 v, plus or minus 10 per cent; 400 cps, plus or minus 5 per cent, single phase

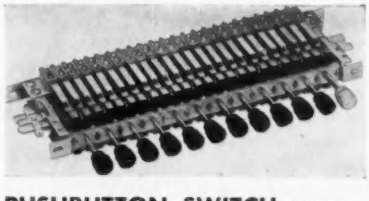
Rated output..... 15 w, 57 v

Input impedance.. 10,000 ohms

Duty cycle..... Full continuous output for 1 hr

Circle No. **25** on reply card

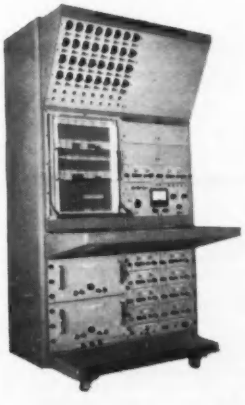
SWITCHES, RELAYS AND TIMERS



PUSHBUTTON SWITCH provides choice of functions.

These unique switch assemblies can

News in Analog Computing...



Rugged amplifiers permit longer reliable operation.

The special, rugged, U-shaped construction of the operational amplifiers is one reason why Electronic Associates' Analog Computers, Type 16-31R have gone over 3000 operational hours without a single chopper failure. These dual D-C Amplifiers feature extremely high gain, wide band width and low noise level. This is but one more reason why EAI Computer Groups set the PACE for stability, accuracy and reliability. You will find this equipment ideal for single purpose use, such as the control of a process—or as a basic general purpose simulator which can be expanded into a large, versatile system. May we forward you complete details on this equipment and on our Computation Center at Princeton, N. J., where computing time, a qualified staff of application engineers and the finest equipment is available on a rental basis. Write Dept. CE-10, Electronic Associates, Inc., Long Branch, New Jersey.

ELECTRONIC ASSOCIATES Incorporated

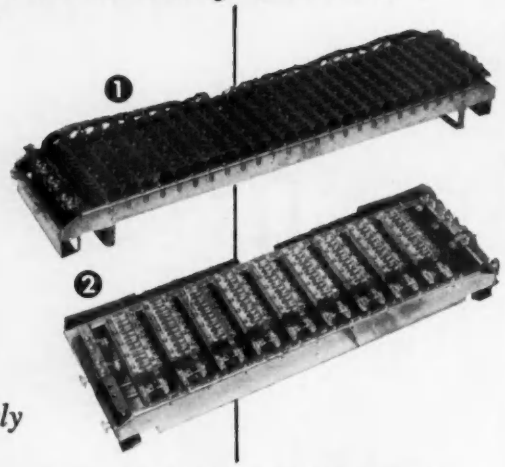
EAI SETS THE P PRECISION A ANALOG C COMPUTING E EQUIPMENT

LONG BRANCH, NEW JERSEY

"Up a Tree" with a Relay Tree?...

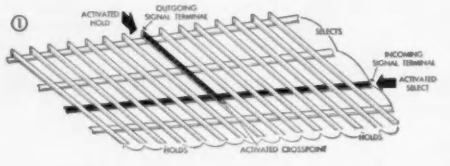
KELLOGG CROSSBAR

solves complex switching problems quickly, easily and inexpensively



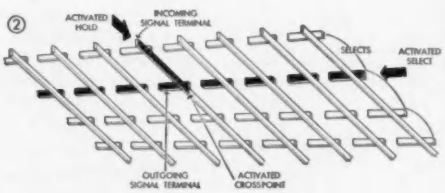
The Kellogg *Crossbar Switch* illustrated below establishes the different types of electrical connections possible. Any cross point can be activated in less than 50 milliseconds by energizing one select magnet and one hold magnet. Standard contact material used in the Kellogg *Crossbar Switch* is palladium (gold can also be provided). Mounting brackets are available which provide drawer-like removal for easy inspection. Circuits can be maintained while the Kellogg *Crossbar Switch* is in the process of switching other circuits.

1



Drawing No. 1 illustrates the basic Crossbar principle which permits any of several incoming circuits to be connected to any of several output circuits. This type of switch can connect any of 60 circuits, 3 at a time, to any of 75.

2



Drawing No. 2 shows a means of switching one incoming circuit to many possible outgoing circuits—accomplished by removing every other vertical. Thus, instead of having one cable terminal at one end of the switch, each remaining vertical has its own cable connection. This type of switch can easily be adapted to switch one circuit to any of 936.

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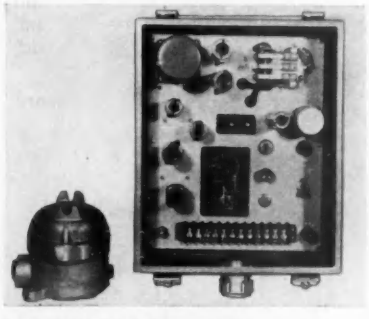
NEW PRODUCTS

be ordered with desired functions and switching combinations and then can be modified in the field by simple adjustments of the stop plate, stop spring, and plunger pin. Choice of functions include interlocking, non-locking, interlock and non-lock combinations, and accumulative locking of some buttons and non-locking of others. Release button restores locked stations.

Available from two to twelve stations, the switches can be stacked up to four high per button. Switch springs, have no forms at the flexing point, enjoy long life. Contracts are fine silver or palladium. Depth behind panel is $3\frac{41}{64}$ in. Distance between pushbuttons is $\frac{5}{8}$ in. Manufacturer states similar switches with illuminated pushbuttons will be available soon. *Switchcraft, Inc.*, 1328 *North Halsted Street, Chicago 22, Ill.*

Circle No. 26 on reply card



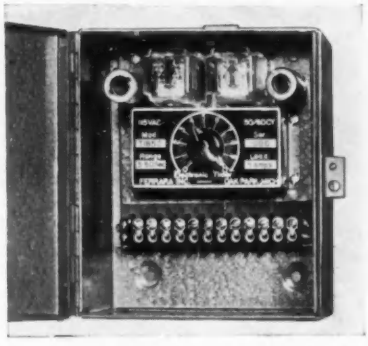
VIBRATION SWITCH protects heavy equipment.

This electronic vibration monitor permits pick-ups responsive to velocity or displacement to be located up to 2,000 feet away from the control unit. Separate time delay relays prevent accidental shutdowns on startup or during brief transient disturbances. Explosion proof transducers are available. Ranges and calibrations are tailored to applications of Model 4 Vibraswitch. Among them: protection of large pump motors, centrifugal compressors, and electrical generating equipment. *The Beta Corp., Forest Avenue at Ridge Road, Richmond 26, Va.*

Circle No. 27 on reply card

VERSATILE electronic timer has 2 per cent error.

Featuring a calibrated dial that can be removed for remote operation, the



T-1 Timer provides interval, delayed action, repeat cycle, and single cycle timing to an error of only plus or minus two per cent. Two timing ranges are available: 0.3 to 25 sec and 0.5 to 50 sec.

Cold-cathode tubes eliminate warm-up time and standby power. Other highlights: built-in regulation, plug-in relays, and 5 amp isolated contacts. Enclosures constructed to NEMA 1A (semi dust-tight) and XII (oil-tight) specifications. *Ferrara, Inc., 8106 West Nine Mile Road, Oak Park, Mich.*

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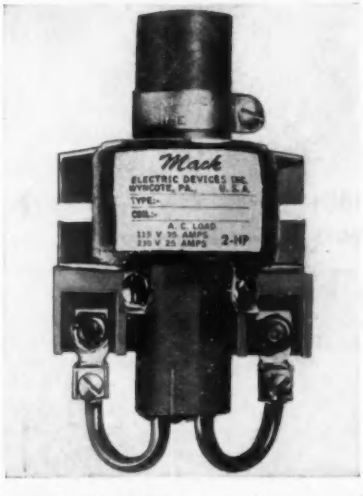


FIBER SHEATH guards rugged mercury plunger relay.

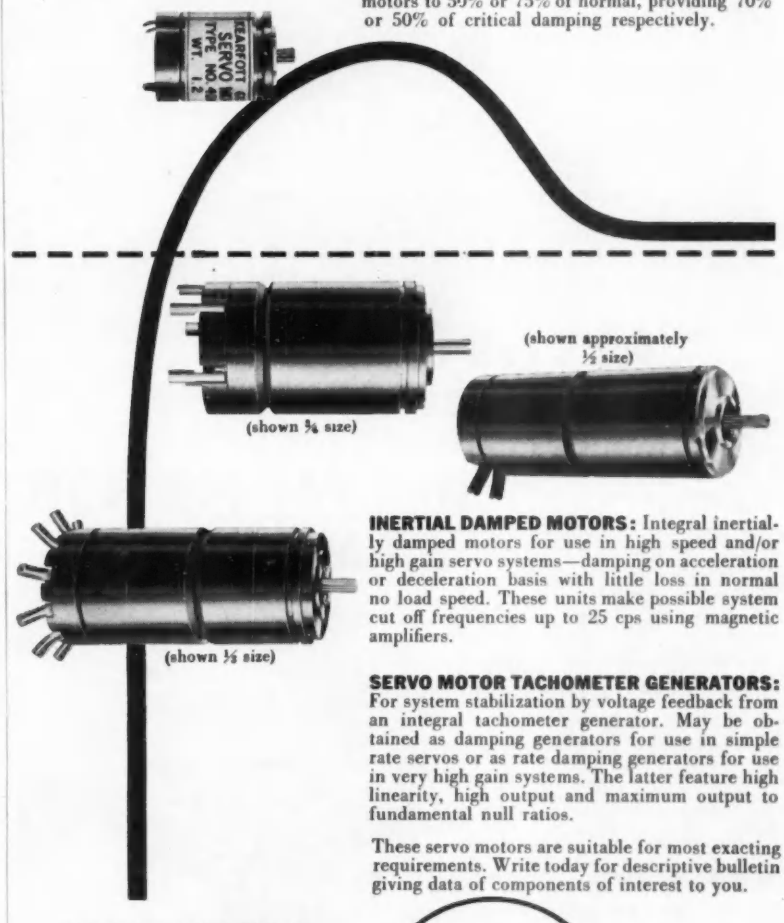
This part-glass, part metal mercury plunger relay will not break under the most trying conditions encountered in shipping, installation, or use. Its heavy tungsten contacts, hermetically enclosed within a fiber cyclinder, and the absence of any exposed arc, make it serviceable in any operating atmosphere. The relay is dust and moisture proof. There is no wear on the coil, frame, or terminal assembly.

There is no one "cure all" for system instability. The desired stability of a servo loop is attained through the proper selection of components that satisfy the various conditions under which the loop will operate. Kearfott offers four basic motors and combinations for providing system stability. All feature high speed of response; low inertia and high stall torque.

SYSTEM STABILITY

SERVO MOTORS: Servo motors with high torque to inertia characteristics possessing (built-in) inherent damping ranging in size from ¾" to 1¾" diameter are available. Low speed, low power motors for use in simple instrument servos where high damping and/or low time constant is required can also be provided.

VISCOUS DAMPED SERVO MOTORS: Provide integral viscous damping for simple instrument servos. Any degree of damping can be provided. These units reduce no load speed of standard motors to 50% or 75% of normal, providing 70% or 50% of critical damping respectively.



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INERTIAL DAMPED MOTORS: Integral inertially damped motors for use in high speed and/or high gain servo systems—damping on acceleration or deceleration basis with little loss in normal no load speed. These units make possible system cut off frequencies up to 25 cps using magnetic amplifiers.

SERVO MOTOR TACHOMETER GENERATORS: For system stabilization by voltage feedback from an integral tachometer generator. May be obtained as damping generators for use in simple rate servos or as rate damping generators for use in very high gain systems. The latter feature high linearity, high output and maximum output to fundamental null ratios.

These servo motors are suitable for most exacting requirements. Write today for descriptive bulletin giving data of components of interest to you.

KEARFOTT COMPONENTS INCLUDE:

Gyros, Servo Motors, Synchros, Servo and Magnetic Amplifiers, Tachometer Generators, Hermetic Rotary Seals, Aircraft Navigational Systems, and other high accuracy mechanical, electrical and electronic components.

Kearfott

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Here is a valuable technical guide that can give you important background information toward solving your remote control problems. The various basic flexible and rigid control combinations, locking devices, fittings, etc., are shown together with information on the custom manufacturing of controls to your specifications.

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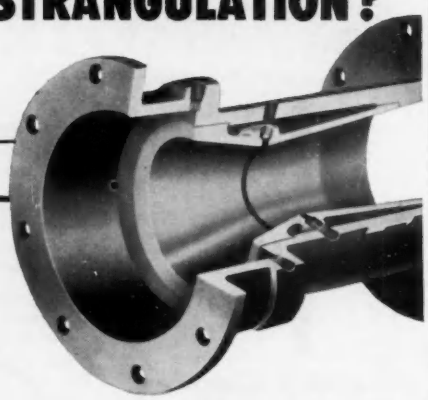

Builders Dall Flow Tube reduces meter head loss where it counts . . . . at the pipe line!

Here's what you can gain by replacing orifice plates with Dall Flow Tubes in your pipe lines: You reduce pumping costs. You avoid the expense of purchasing over-sized pumping equipment. You gain adequate process flows without building new and costly piping layouts. With it, you obtain top repeatability and long life.

Builders Dall Flow Tube gives maximum pressure recovery — more than any other velocity increasing flow tube. It's compact and economical, too. For complete details, write for Bulletin 115-L1. Builders-Providence, Inc., 528 Harris Avenue, Providence 1, Rhode Island.

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DIVISION OF B-I-F INDUSTRIES, INC.

BUILDERS IRON FOUNDRY • PROPORTIONEERS, INC. • OMEGA MACHINE CO.

BIF METERS FEEDERS CONTROLS

NEW PRODUCTS

The plunger, made of special magnetic stainless material within a ceramic liner, assures positive displacement of mercury. Operation is quiet and fast: 60 millisec to close and 40 to open. *Mack Electric Devices, Inc., Wyncote, Pa.*

Characteristics

Dimensions.....4½ x 2¼ x 2⅜ in.
Contacts..35 amp at 115 vac, 25 amp at 230 vac, and 10 amp at 115 vac

Circle No. 29 on reply card

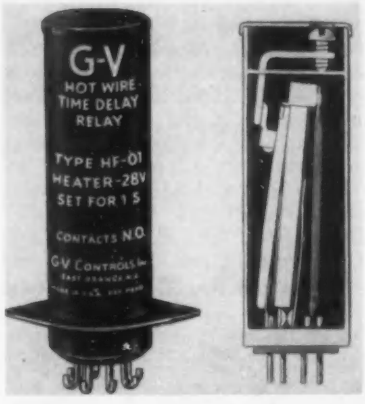
24-HR TIME SWITCH controls intermittent operations.

The timer dial on this fully automatic switch rotates once every 24 hrs. It is scaled in fifteen minute intervals; each graduation has a non-removable trip lever that is moved into or out of the dial. A complete timing schedule therefore can have as many as 48 "on" and 48 "off" operations. An accessory calendar device gives selective cutout for any non-working day out of seven. Manufacturer indicates adaptability for marginal operation of oil well pumps and cycling of processing equipment for heating, ventilating, and air conditioning systems; and for stokers and gas burners. *Zenith Electric Co., 152 W. Walton Street, Chicago 10, Ill.*

Characteristics

Overall dimensions...8¼ x 6½ x 4½ in.
Contact capacity.....1000 w
Operating voltage.110 or 240 v 60 cps
Contact arrangement.....SPDT

Circle No. 30 on reply card



HOT WIRE RELAY has wide time range, rapid recovery.

The timing of this delay relay switch, which operates on the hot-wire principle, is shorter than that of conventional bimetallic relays and longer than that of the slow-acting type of magnetic relays. It is adjustable from $\frac{1}{10}$ to 5 sec by a screw accessible from the top, even though the relay is hermetically sealed.

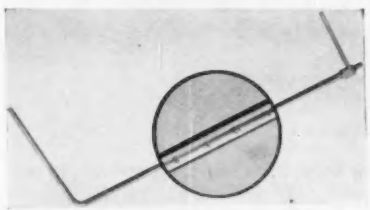
Recovery occurs rapidly, and the relay is ready for a new cycle after only a few seconds' cooling. Standard heater voltages energized from ac or dc range from 6.3 to 28. Designated as Series H, these relays are compensated for ambient temperatures from minus 70 to plus 100 deg. C. *G-V Controls Inc., 28 Hollywood Plaza, East Orange, N. J.*

Characteristics

Diameter	$\frac{3}{4}$ in.
Height	$2\frac{3}{8}$ in.
Weight	1 oz.
Contract rating	3 amp at 115 vac
Contact arrangement	Spst, NO or NC

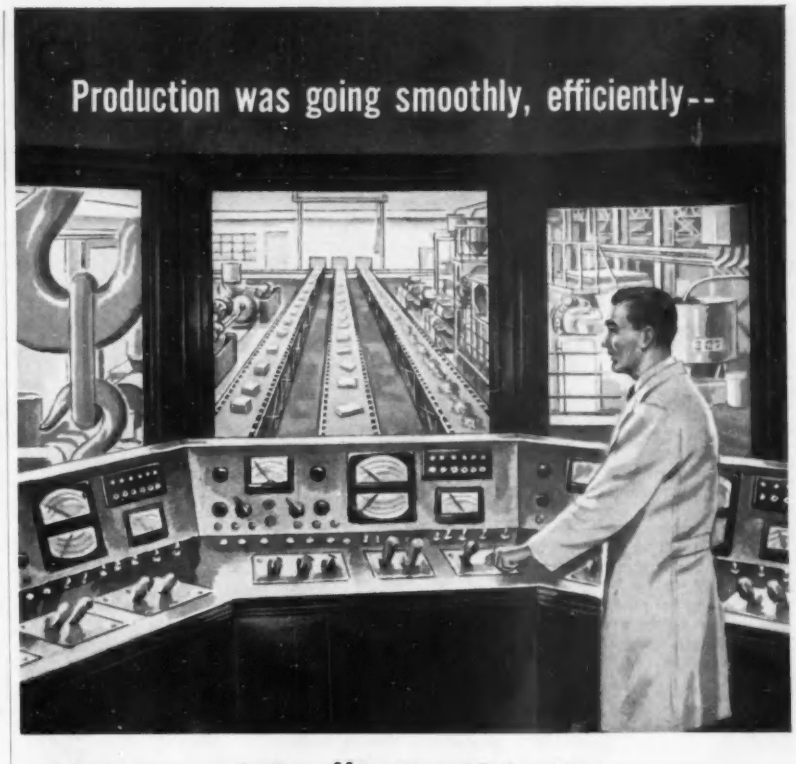
Circle No. **31** on reply card

SOME NEW TRANSDUCERS



PITOT'S EXTERNAL graduations simplify measuring.

Air velocity and static pressure measuring with a pitot tube are standard



Then . . . a tube "let go" in the electronic control equipment!

And when a "control" stops operating there's no production, or, at best, only limited output. That's one of the important reasons why RCA "Special Reds" are used in industrial electronic equipment —they *minimize production slow-downs and shutdowns due to tube failure!* They have built-in "spare" life. Only RCA "Special Red" Tubes offer all these advantages:

- *extra long-life—10,000 hours minimum*
- *exceptional stability throughout life—even under extreme variations in humidity and temperature*
- *extreme uniformity of characteristics from tube to tube*
- *high resistance to shock and vibration through rigid construction.*
- *selected high quality materials and superior workmanship*

RCA "Special Red" Tubes are recommended for initial designs in industrial electronic equipment. They can be used as replacements in existing circuits where there is a prototype operating under conditions within the ratings of the "Special Reds," and where 10,000-hour life, exceptional stability, and extreme uniformity of characteristics are specially needed.

Contact your local RCA Tube Distributor today for your copy of the booklet "RCA Receiving-Type Tubes for Industry and Communications."

RCA-5690—Full-Wave Vacuum Rectifier.

RCA-5691—High-Mu Twin Triode. Similar to RCA-6SL7-GT, but has twice the heater current.

RCA-5692—Medium-Mu Twin Triode. Similar to RCA-6SN7-GT.

RCA-5693—Sharp-Cutoff Pentode. Similar to RCA-6SJ7.

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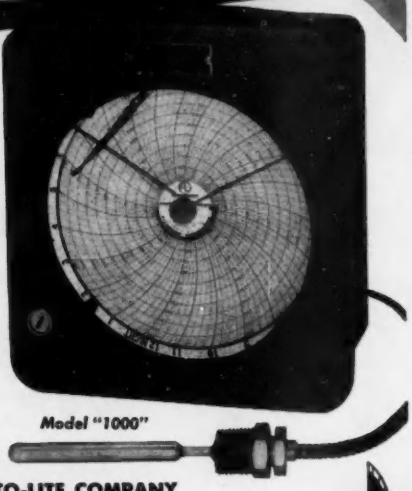
TEMPERATURE RECORDING...

Newly designed, Model "1000" Auto-Lite Recorder gives permanent proof of temperature behavior. • 6" clear reading chart; various standard ranges from minus 40°F. to plus 550°F. • 3 standard types; choice of 24-hr. or 7-day cycle. • Electric or mechanical chart drive. • With capillary tubing for remote reading. Priced from $49.50.

Send for new catalog describing many styles of Auto-Lite temperature Recorders and Indicators.



Model "1000"

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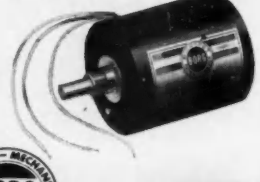
Borg 1100 Series Micropots

Accurate, dependable. long-lived. Has 9 inch coded leads for easy installation. Offers your products a competitive price advantage.



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ELECTRONIC — MECHANICAL BORG EQUIPMENT

Built by Borg

procedure. But tests performed with this externally graduated (inch increments) and accurately sized static hole tube simplify traverse measurements and location of the center of duct. Standard stainless steel models range in length from 12 to 60 in. They meet NAFM and ASH&VE specifications. Priced from $12.50. *F. W. Dwyer Mfg. Co., P. O. Box 373, Michigan City, Ind.*

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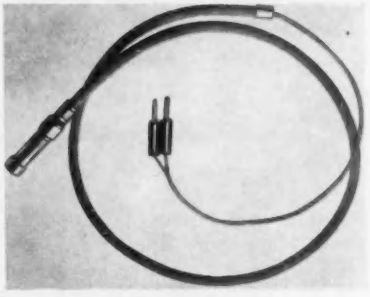
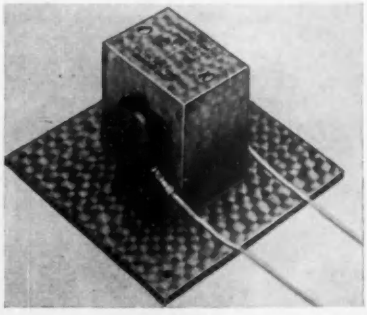


PIEZOELECTRIC CRYSTALS shine in ultrasonic range.

This ultrasonic level intensity transducer (first cut) develops a high level dc output that gives an energy measurement when connected to a dc meter. The probes are accurate from 100 to 800 kc, and retain their usefulness as detectors to 2 ms (Model LU 100) or 3 mc (Model LU 101) with an approximate indication of the ultrasonic intensity. The small probe houses a piezoelectric element, crystal detector, and low-pass filter, banana plugs terminating a shielded cable.

High frequency mechanical vibration testing highlights the applications



of this piezoelectric vibration (second cut). A rigid stack of transducers gives Model AT-10A a balanced inertia design that minimizes the effect of loading masses. Tests on structures up to 3 oz can be handled. The transducer is resonant-free up to 27 kc, its fundamental resonant frequency. Sen-

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(64) ENGINEERING PSYCHOLOGY. The Franklin Institute. Brochure, 18 pp. This is the first of a series of booklets that will tell about The Franklin Institute's specialized technical services to industry. It defines engineering psychology as "the scientific analysis of the measurement of man in relationship to machines", employing "scientific methods, laboratory techniques, and statistical data in the study of man-machine systems". The work of the institute's Laboratories for Research & Development is discussed.

(65) CONAX DEVELOPMENTS. Conax Corp. Catalog 1542, 20 pp. Illustrated is Conax's array of thermocouple assemblies and pressure sealing glands. A thermocouple protected by a Conax Speedwell is said to have a lag factor only seven times that of a bare thermocouple, as compared to 50 for a standard well. New entries include thermocouple head and these types of thermocouples: pipe clamp, Teflon covered, and iron and copper constantan.

(66) STRAIN GAGES, ETC. Baldwin-Lima-Hamilton Corp., Testing Equipment Dept. Booklet S-E 3-55 25M, 12 pp. This is called a "domestic price list" but it really is much more. It defines flat grid and wrap-around gages, suggests considerations in selecting a gage, and gives a price-specification chart that's credit to the booklet's designer. Instruments, accessories, and cements receive equally fine treatment.

(67) INSIDE AC SPARK PLUG DIV. General Motors Corp., AC Spark Plug Div. Booklet A-2367, 9 x 12 in., 16 pp. This neat and colorful booklet, strewn generously with pictures, tells about AC's engineering and electronics groups, labs and test equipment, model shop, and field service.

(68) 350 INSTRUMENTS. Central Scientific Co. Catalog supplement, 64 pp. Handy name for this extensive rundown of Cenco specialty instruments is "Labaratus". Its 350 entries supplement the complete price list of 14,000 items. In the back are order blanks and a current price list. Some items get full-page play.

(69) INDUSTRIAL CONTROLS. General Controls Co. Industrial catalog, 44 pp. General Controls calls this the most complete catalog it has ever published. It is one of those rare catalogs that contain an index. In fact, this has two indexes, one for names, the other for numbers of the items described. These include electric valves for gas, air, oil, water, steam, and other fluids; brand new three- and four-way pneumatic valves for machinery; air pressure regulators, etc. A sizable portion of the products covered has never been catalogued before.

(70) LIMIT SWITCHES. R. B. Denison Mfg. Co. File-folder catalog, 10 pp. Features of these heavy duty Loxswitches include twice as much contact pressure (50-100 per cent faster "break"), long contact life, 70 deg safety overtravel, interchangeable mountings and levers, and choice of 150 levers. Information on wiring, amperes, operations, and electrical characteristics are given for 11 switches (five normally opened or normally closed models and one neutral model).

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(71) SOLVING CONTROL PROBLEM. CDC Control Services, Inc., Automation Engineering Bulletin, 4 pp. Simulating conditions faced by an in-flight airplane engine posed problems of high resolution, high frequency of response and full analysis to determine optimum control functions. CDC's bulletin tells how these problems were solved. Oscillograph and pilot-model records were balanced against each other with favorable results. Here, in four pages, is a succinct description of the instruments used and results obtained. Among the latter: steady state error and transient pressure held within plus or minus one per cent of set point.

(72) THERMOSTATIC CONTROLS. Lawler Automatic Controls, Inc. Bulletin C-6, 8 pp. Thoroughly described and clearly illustrated in this booklet are temperature regulators, tempering valves, thermometers, shower mixers, water controllers, water pressure equalizers, photographic control assemblies, and special equipment for hospitals.

(73) MOTOR-GEAR TRAIN. John Oster Mfg. Co., Avionic Div., 22 x 17 in. sheet. Feature of this large specification sheet is the new homogenous unit comprising a power motor and gear train. This is a new principle, according to Oster. Output speed ranges from 10,000 to 0.3 rpm, torque is 100 lb-in. at 523:1 and 1,600 lb-in. at 10,500:1. Four models: 28 and 115 vac, and 28 and 115 vac, 400 cycles. Also described: synchros, servo torque units, tachometer generators, etc.

(74) FERRAMIC MAGNETIC CORES. General Ceramics Corp. Folder, 4 pp. Graphs demonstrate performance of Ferramic "S-1" under various conditions and circumstances. There is a table of magnetic properties and one of core sizes.

(75 DC AMPLIFIER. Hagen Corp. Bulletin MSP-111.1, 12 pp. Direct conversion into analog computer inputs or indirect conversion (through a data conversion unit) is possible with this Model "P" amplifier. Other control applications for this fast-response unit include telemetering, preamplification, stress and temperature-measurement, and temperature difference. Error is plus and minus ¼ to ½ per cent of input range.

(76) CONTROLLED VOLUME PUMPS. Milton Roy Co. Bulletin 953, 24 pp. Pumps that meter water treating chemicals for industrial uses are the subject under discussion here. Their error is plus or minus one per cent at the point of application. Tabulated data include capacity and pressure ranges, speed and stroke lengths adjustments, and the chemicals themselves. Chemical feed systems, water treating systems, and boiler water treating are considered.

(77) DU MONT INSTRUMENTS. Du Mont Laboratories, Inc. "Quick Reference Catalog", 8 pp. Cathode-ray oscillographs and their accessories in this booklet are sectioned according to low and high frequencies. Specifications are complete.

(78) MULTIPLE-PRESSURE READOUT. Fischer & Porter Co. Catalog 58-15, 12 pp. As many as 200 pressures can be sampled and recorded and magnitudes converted to digital form by this readout system, whose accuracy is one part in 2,000. Recording is in a typewritten column or in punched tape. Data may be read out in binary form on magnetic tape.

Also, Catalog 2, 24 pp. Generous specifications for process control instruments that F.&P. has standardized and stocked for shipment from plants in four cities. Data on various flow meters and indicators, pneumatic recorders and controllers, pressure regulators, flow rate gages, chemical feeders, and specific gravity testers include dimensions, prices, capacities, and construction materials.

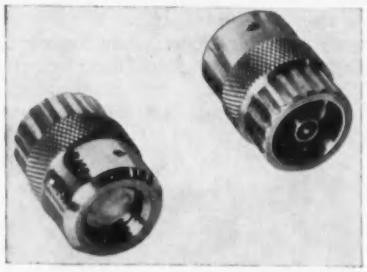
(79) TELECOMPUTING. Telecomputing Corp. Bulletin TC-103, 8 pp. Presented here is news about the Teleplotter, a high-speed electronic digital device that displays experimental data in graphical form. It follows the grids on coordinate paper (linear or non-linear), "stretching" with the paper when necessary. Plotting area is 26 x 54 in., scale factors are 1, 2, 4, and 5, and plotting speeds are 50 points per min at spacings up to 10 mm, and 72 at spacings up to 5 mm.

(80) NEWS FROM IRC. International Resistance Co. Catalog Data Bulletin D-2, one sheet of specifications for sealed precision voltmeter multipliers; CD Bulletin T-1, 4 pp., information on resistance strips and concentric disc resistors; CD Bulletin B-9, one sheet of data on half-watt molded deposited carbon resistors; and CD Bulletin SR-3, 6-pg. gate-fold, data on Varistors (asymetric non-linear resistors).

(81) RELAYS AND SWITCHES. Automatic Electric Sales Corp. Catalog supplement, "Relay Highlights No. 4," one sheet. Here's how two automatic electric rotary stepping switches proved out in a Cincinnati drilling machine company.

sitivity: 2.3 microin./55v input. Acceleration range: ½ g at 1 kc and 50 g at 10 kc.

Another application for the piezoelectric crystal results in a wide-range, fast, transient pressure measuring



transducer (Model P 450, third cut). It is $\frac{9}{16}$ in. in diam and terminates in a miniature coax connector. The output feeds into a cathode follower. Sensitivity: 500 mv/psi. Pressure range: 0.001 to 500 psi. Frequency range: 25 to 20,000 cps. Temperature range: minus 40 to plus 90 deg C. Natural resonant frequency is 185 kc. *Gulton Mfg. Co., Metuchen, N. J.*

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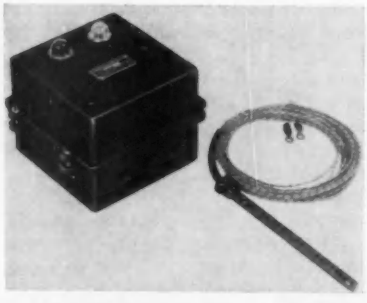

THREE-PART system shadows liquid level.

Three components comprise this simple liquid-level system: a compact power and control box, an interconnecting cable, and the tiny thermistor sensing element enclosed in a corrosion-resistant housing. The self-heat generator in the thermistor dissipates with liquid and the consequent change in thermistor resistance operates a relay. Relay operation performs visual, aural, or control functions as required. Advantages of the design: no electrical contact with the liquid, no adjustments for different fluids, non-electronic, no moving parts. Differential levels can be detected to $\frac{1}{16}$ in. Operation is unaffected by cable lengths (#12 AWG, copper) exceeding 1,000 ft.

The control unit comes in vapor-

Time delays in automation circuits

AGASTAT

Time / Delay / Relay

When automatic machinery and circuits must be timed with repetitive accuracy (from 0.1 second to ten minutes or more) you'll find a sure, reliable answer in AGASTAT electrically-actuated pneumatically-timed time delay relays.

The AGASTAT is
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- available in models which offer delays on energizing and de-energizing, two-step delays, manually-actuated time delay switch, remote push button control.

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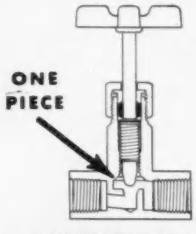

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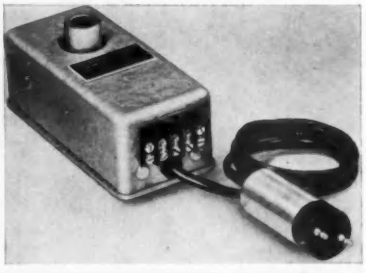

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Linearity.....Function of capacitor configuration
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Characteristics (standard units)

Pressure range.....0-2 to 0-4,000 psi
Potentiometer resistance.....500 to 20,000 ohms
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Linearity..Plus or minus 0.75 per cent
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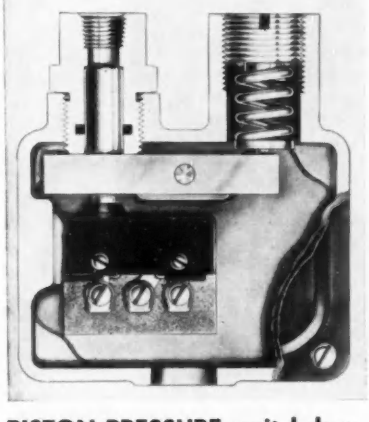

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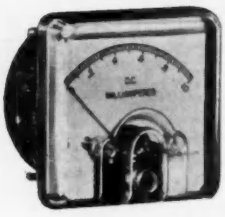

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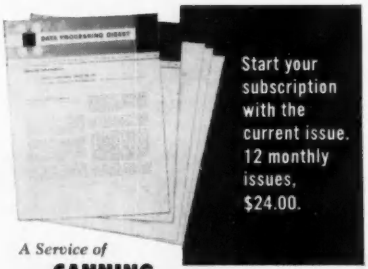

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WHAT'S NEW ABSTRACTS

Transistors Can Replace Electron Tubes

From *"The Field-Effect Transistor", by I. M. Ross, Bell Telephone Laboratories. "Bell Laboratories Record", May, 1955*

Though commonly available transistors are in many ways more desirable than electron tubes (small size, ruggedness, low weight, no heater power, possibly much longer life), certain disadvantages have limited their use. Low input impedances in the order of hundreds of ohms have meant low voltage gains and poor power sensitivities. Long transit times (the current-carrying holes and electrons must diffuse through the solid-state semiconductor) have meant relatively low frequency response. Thus, transistors have had poor gain at radio frequencies.

The field-effect transistor described here operates on a principle that is quite different from that of the familiar point-contact and junction transistors. It promises to retain all the advantages of the transistor while eliminating all the disadvantages. It was during an investigation of the field-effect principle that Bardeen and Brattain invented the point-contact transistor.

In an "*n*-type" semiconductor, *n* standing for negative, conduction is due primarily to the movement of electrons. In a "*p*-type" semiconductor, *p* for positive, conduction is due primarily to the movement of "holes", which may be considered to be particles having about the same mass as an electron but with a positive charge. Germanium or silicon can be made either *n*- or *p*-type, depending on the chemical elements that are added as impurities during growth of the crystal. A *p-n* junction is nothing more than the interface between a region of *n*-type conductivity and a region of *p*-type conductivity.

If the *p* side of a *p-n* junction is made positive with respect to the *n* side, electrons move across the junction from the *n* to the *p* region while holes move in the opposite direction. Under these conditions a current flows and increases with increasing applied voltage; the junction is said to be biased in the "forward" direction and has a low impedance. If the applied voltage is reversed, the junction is biased in the "reverse" direction, has a high impedance, and allows practically no current to flow.

Actually, a very small constant current on the order of a few microamperes flows when reverse bias is applied. This current is independent of the magnitude of the bias and is therefore called the "saturation" current. The electric field in a region close to the junction itself is high enough to pull all the charged carriers out of that region. Because it contains no current carriers, it cannot support conduction and acts like an insulator. The *p* and *n* junctions are separated, therefore, by an insulator whose thickness varies with the reverse voltage applied. Thus the junctions act like the plates of a capacitor separated by the total width of the space-charge region. The effective capacitance varies inversely with the applied reverse voltage.

The field-effect transistor, Figure 1, has a *p-n* junction on both sides of an *n*-type slab. Consider what happens if the *p*-regions are short circuited to the left end of of the *n* region and a positive potential is applied to the right end. A current, *I*, flows from right to left as shown—electrons flow from left to right. The left-hand contact is the "source" of these electrons and the right-hand contact "drains" them out of the semiconductor. Because the *n*-type material has resistance, the current produces a voltage drop in the material,

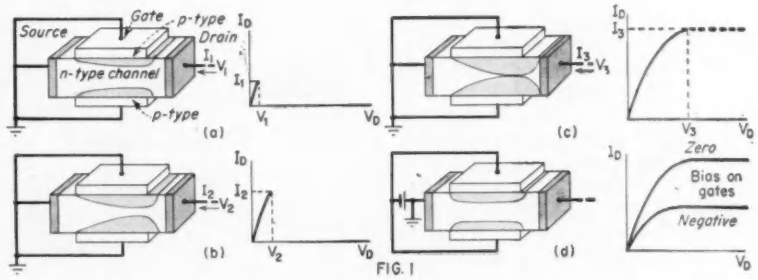

FIG. 1

the potential becoming more positive toward the drain. But, because the *p* regions are connected to the source, this same potential appears across the *p-n* junctions in a direction that biases them in reverse.

Thus, a space-charge region that spreads into the *n*-type material gets wider toward the drain, Figure 1A. The current is constrained to flow in the center of the slab, called the "channel"; hence the resistance from source to drain is greater than with no potential applied. As the drain potential is increased, the space-charge regions continue to extend, further increasing the resistance from source to drain, and the current-voltage curve bends as shown in Figures 1A and 1B.

Finally, a condition is reached in which the space-charge regions from opposite sides meet, as in Figure 1C. This is called the "pinch-off" condition, and current is at a maximum. If the drain potential is increased beyond this point, the space-charge regions tend to meet over a finite length and the resistance increases very rapidly. Hence the current cannot increase appreciably. On the other hand, the resistance cannot increase faster than the voltage to make the current decrease, because then the space-charge regions would contract, reducing the resistance and increasing the current again. Thus the current becomes constant above pinch-off.

As shown, the *p*-type regions cause the conducting portion of the *n*-type material to be narrowed down. For this reason, the *p*-type regions are called "gates".

If a negative biasing voltage is applied between the gates and the source as in Figure 1D, the initial resistance will be higher and the current will always be lower than when the gates were short circuited to the source (zero gate voltage).

Figure 2 is a set of characteristic curves taken from an operating unit. The input or gate-to-source impedance is essentially that of a *p-n* junction biased in reverse. In practice, it can be of the order of 10 megohms. If this

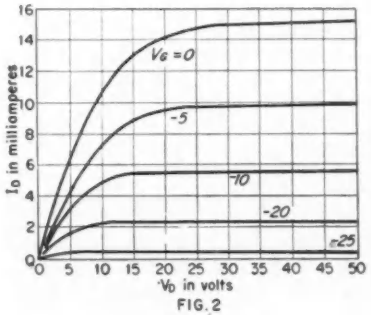

FIG. 2

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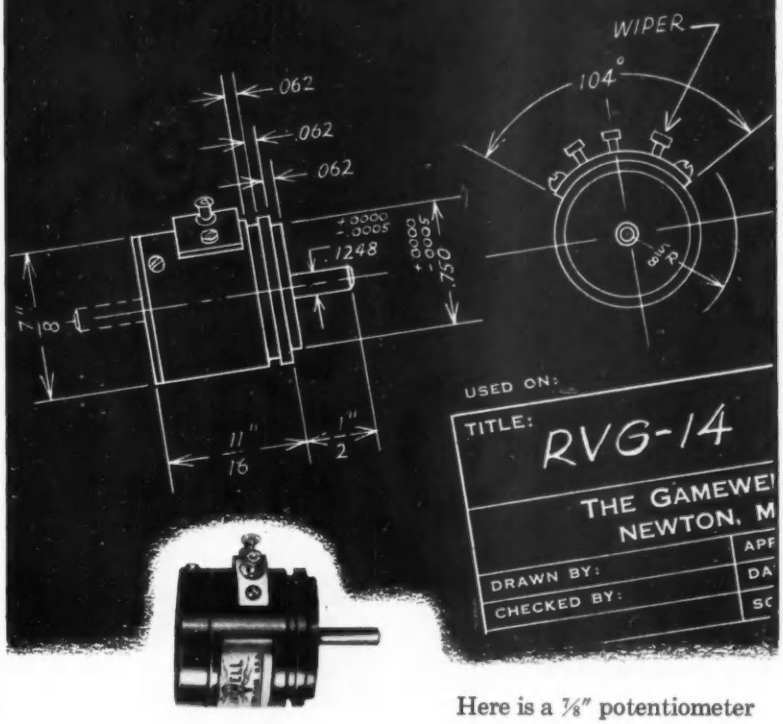

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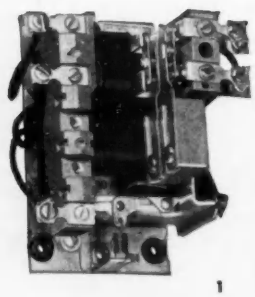

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ABSTRACTS

transistor is operated near zero gate voltage and above the knee of the curve with a load resistance of 10,000 ohms, a voltage gain of ten results. This requires a fairly high *B* supply, similar to that for electron tubes. Because of the different input and output impedances and voltages, the power gain calculates to be 10,000 or 40 db. The field-effect transistor, then, is very much like a pentode tube.

The other advantage of the field-effect transistor is that it causes the current carriers to move in an electric field, rather than by simple diffusion. Since velocity in a field is much higher than that in diffusion, the transit time is shorter. Field effect transistors have operated successfully at frequencies as high as 50 megacycles per sec with a transconductance of several thousand micromhos.

Gyro Rotor is Part of Motor

From "Symmetrical Aircraft Gyroscope Motor for Optimum Performance", by H. C. Wendt, Instrument Dept., General Electric Co. ASME Paper No. 55—S-26

This paper describes the design features and development of a new gyroscope motor. Essentially, two motors are mounted back to back with common rotor shaft and bearings. The stators are mounted on a small flat plate with integral bearing pivots that replace the usual ring-type gimbal. The stators are kept small to minimize the differential mass shift that accompanies temperature changes.

The rotor is the gyroscope rotor itself. Simple hysteresis rings are spun into the titanium alloy rotor to produce a synchronous motor with adequate torque. Sintered tungsten alloy rings shrunk on the rotors concentrate two-thirds of the rotor's inertia at its rim.

The rotor has a maximum diameter of 2⅛ in., weighs 1 lb, and has an angular momentum of 4 million gr cm² per sec at 24,000 rpm, synchronous speed. Hermetic sealing in helium and the small rotor diameter allow acceleration to synchronous speed in 1 to 1½ min. The motor consumes only 15 watts, causing a temperature rise of only 18 deg C in helium. This helps to assure longer bearing life and to minimize the thermal mass-shifts that cause random drifts in gyro position. The random drift in this case has been held to plus or minus 2 or 3 deg per hr.

Tower of Anti-Babel

MACHINE TRANSLATION OF LANGUAGES. *Edited by William N. Locke and A. Donald Booth.* 6 x 9 *in.* 243 *pp. Published jointly by Massachusetts Institute of Technology and John Wiley & Sons, Inc.* $6.00.

It was Warren Weaver of the Rockefeller Foundation, one of the first to see a future and a purpose for machine translation, who laid the foundation for this Tower of Anti-Babel, a tower that may cause to come full circle the Biblical story of how an angry God confounded men's tongues. And it is a movement in which scientist-linguist Norbert Wiener *did not* have a hand. In fact, Wiener told Weaver: "I am frankly afraid the boundaries of words in different languages are too vague and the emotional and international connotations are too extensive to make any quasimechanical translation scheme very hopeful."

The fourteen mathematicians, computer specialists, scientists, and linguists whose essays make up this pioneering treatise have covered machine translation as exhaustively as a new field can be covered. Often it seems as if they had waded into an area whose data has been enriched by time, instead of one whose surface is just now cracking.

Weaver's memorandum on "Translation" is reprinted in full. This 1949 document is historical. To most of the 200 people who read it when it was first written, it was a revelation. Weaver's assumption that machine translation is possible was based on the observation that in all languages there are elements that are "to some significant degree independent" of those languages, that "there are certain invariant properties which are, again, not precisely but to some statistically useful degree, common to all languages." And with this in mind, Weaver issued a call for "statistical semantic studies".

It is to their credit that the essayists stay, more or less, within the boundaries established by the chapter headings. There is repetition, of course, but this cannot be avoided when experts meet. Even more admirable, for the most part they do not refute one another.

Certainly, literary works of art are not destined (at this point, anyway)

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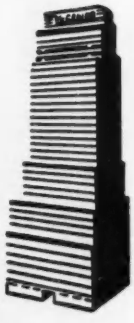

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for machine translation. Only a human translator can catch the nuances, innuendoes, and subtleties, and bring to an English-reading audience the beauty of, say, a French or Russian novel. But as Weaver, Locke and Booth (MIT and Birbeck College, London, respectively), Anthony G. Oettinger (Harvard), and others point out, MT can tackle technical books and papers with an assurance born of the confidence that it, and only it, can do a fast and adequate job.

As Oettinger says, "There is no doubt that [MT is] fully adequate to reveal to a reader whether the original paper was one relevant to his purposes or one worthy of further consideration," and later, "It is interesting to conjecture that such a reader is, in effect, mastering something of Russian sentence structure without having to burden his memory with a Russian vocabulary."

Most writers agree that a magnetic drum would serve best as a glossary, since its area far exceeds either magnetic tape or punched cards. Some, particularly Booth, Locke, and R. H. Richens (Commonwealth Bureau of Plant Breeding and Genetics, England) suggest storage of word stems only. These would be printed by the output typewriter together with symbols denoting case, gender, tense, and other syntactical clues.

It is impossible here to outline the ideas of each essayist. It is interesting, however, to indicate a few. Leon E. Dostert (Georgetown University), for example, says of MT: "It seems clear to me, at least, and to some of my colleagues, that the linguistic aspect of the general problem is the primary one, and is, therefore, the one on which the main effort should be focused at this time."

Luitgard and Alex Wundheiler (Illinois Institute of Technology) "suggest a set of terms, mostly borrowed from logic, that are invariant under translation." Their chapter is divided into sections on "The Necessary Ingredients of Language", "The Necessary Ingredients of Syntax", and "Actual Grammar of National Languages".

Locke, in his chapter on "Speech Input", could be said to dazzle even science fiction writers. His translating chain consists of a spoken input, typewritten output, typewritten input, and spoken output. His ideas are purely conjectural, but so are those of most of the writers here. And like the others, those on speech translation via machine are downright convincing.

Covering the Semiconductor

TEN YEARS OF SEMICONDUCTING MATERIALS AND TRANSISTORS. *A bibliography compiled by N. L. Meyrick and classified by G. Roman, both of the Research Dept. of Pye Limited, Cambridge, England.* 8½ x 11 *in. Published by Foister & Jagg, Cambridge.*

The depth of this compilation is really astounding. The six sections in its manuscript-size, double-column format deal with "Semiconductors—Theory and Measurements", "Processing of Semiconductors", "Transistors", "New Forms of Transistors", "Rectifiers and Diodes", and "Other Semiconducting Devices".

And even this doesn't begin to illustrate the work's profoundity. The foreword, written in 1954, declares that "the utilization of controlled electron movement in solid materials represents one of the most revolutionary discoveries of the past decade," and this statement certainly is done justice by the lists that follow it.

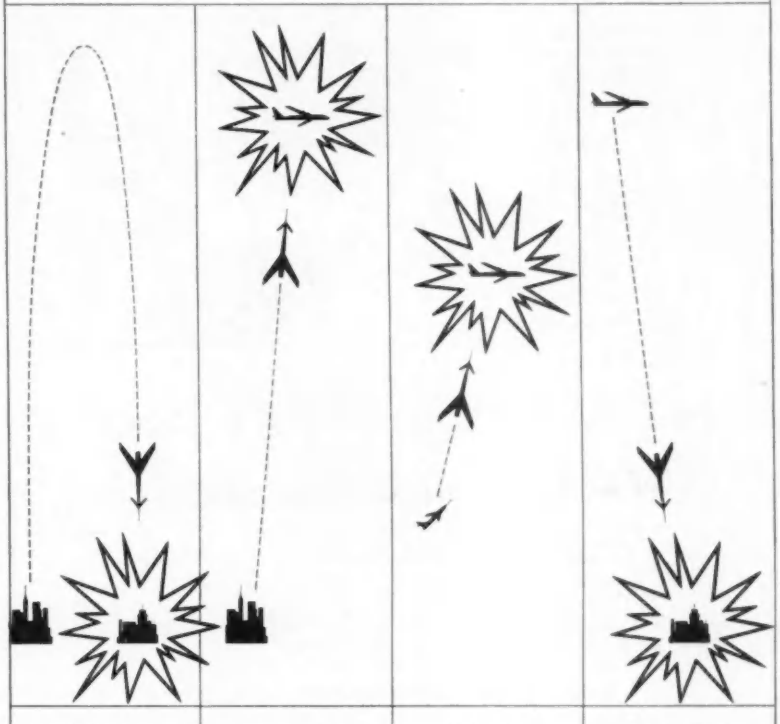
For instance, in the first section, on semiconductors, there are 132 entries under "Pure Scientific Interest" and 85 under "Compounds with Semiconducting Properties in General". In the transistor section there are 63 entries under "General Information" and 95 under "Circuitry". And in that on rectifiers are 43 entries under "Semiconductors Used for Rectification". The book's thoroughness is driven home further by single entries for "Semiconductors — Noise Measurement and "Other Semiconducting Devices—Measurement of Photoelectric Phenomena".

THE TRANSISTOR: SELECTED REFERENCE MATERIAL ON CHARACTERISTICS AND APPLICATIONS. *PB* 111054. 800 *pp. Office of Technical Services, U.S. Department of Commerce, Washington 25, D. C.* $20.00.

This is the work of Bell Telephone Laboratories, which in 1951 was under contract to the Army Signal Corps to supply information on the transistor to the military services. Theories, properties, circuit design principles, applications, and characteristics of types of transistors are supplemented with technical reports. Contributors include several leading transistor authorities.

The material has been released to industry by the Commerce Dept.'s Office of Technical Services.

GUIDED MISSILES



Nearly all guided missiles require specialized and highly advanced electronic systems of miniature proportions. These systems may include servo-amplifiers, microwave receivers and transmitters and extremely efficient though compact power supplies. The performance objectives for this equipment would be difficult in conventional engineering applications.

At Hughes, the achievement of such objectives in the very limited space and under stringent environmental conditions of the modern guided missile provides an unusual challenge to the creative engineer.

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Scientific and Engineering Staff

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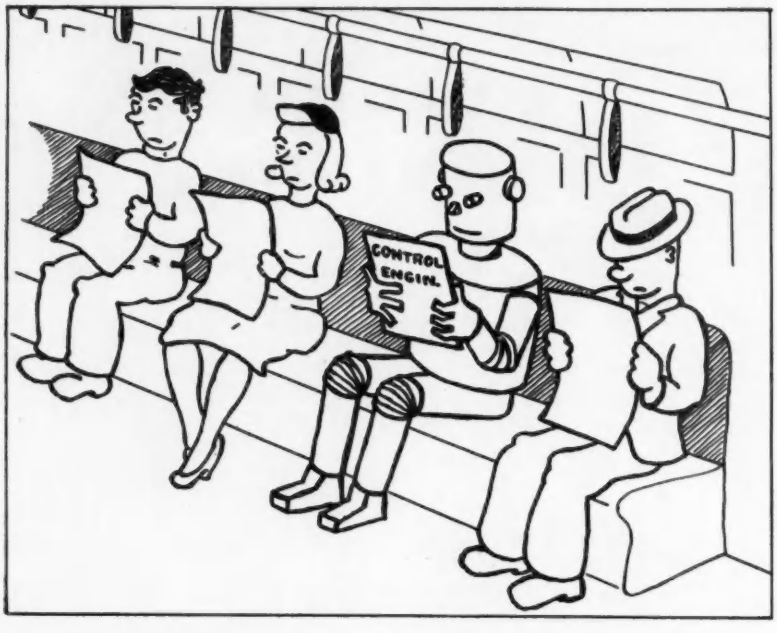
Culver City, Los Angeles County, California



DON'T MISS OUR NEXT ISSUE

With its September issue CONTROL ENGINEERING becomes one year of age. To commemorate the occasion —and reaffirm our publishing credo—this issue will carry a series of articles showing how control spans the production and processing industries. Under the banner of Production-Process Control you'll read:

- **"The Common Denominator"**—an editorial by Don Campbell
- **Three basics to production and processing:**
  1. establishing a control engineering department
  2. facing up to labor problems in automation
  3. using data processing in inventory control
- **Four dual articles that link the field:**
  1. Building blocks for control (timers and monitors)
  2. systems in control (machine tool and refining)
  3. power in control (magnetic amplifiers and valves)
  4. design in control (machine acceleration and process sampling)

Coincidental with this Production-Process Control issue will be two important control field shows: the Production Engineering Show in Chicago, Sept. 6-16, and the Instruments Exposition in Los Angeles, Sept. 10-16. If you miss our September issue because you're taking in these shows, visit CONTROL ENGINEERING's booth at either one. But whether on a business or a vacation trip, it would be a good idea to have your copy forwarded. We think you'll find it good reading in a hotel, houseboat, hammock, or subway.

WHAT'S AHEAD: MEETINGS

AUGUST

American Institute of Electrical Engineers, Pacific General Meeting, Butte, Mont. Aug. 15-19

SEPTEMBER

Production Engineering Show and Machine Tool Show, Navy Pier and International Amphitheater, Chicago, Ill. Sept. 6-16

Instrument Society of America, 10th Annual Conference and Exhibit, Shrine Exposition Hall and Auditorium, Los Angeles, Calif. Sept. 12-16

Association for Computing Machinery, Annual Meeting, University of Pennsylvania, Philadelphia, Pa. Sept. 14-16

Institute of Radio Engineers, Professional Group on Nuclear Science, Second National Annual Meeting, Oak Ridge, Tenn. Sept. 14-16

International Analogy Computation Meeting, Brussels, Belgium. Write P. Germain, Universite Libre de Bruxelles, So. av. Fr. Roosevelt, Brussels, Belgium. Sept. 27-Oct. 1

American Institute of Electrical Engineers, Industrial Electronics Conference, Rackham Memorial Auditorium, Detroit, Mich. Sept. 28-29

OCTOBER

National Electronics Conference, Hotel Sherman, Chicago, Ill. Oct. 3-5

American Institute of Electrical Engineers, Fall General Meeting, Morrison Hotel, Chicago, Ill. Oct. 3-7

Society of Automotive Engineers, Golden Anniversary Aeronautic Meeting, Aeronautic Production Forum and Aircraft Engineering Display, Hotel Statler, Los Angeles, Calif. Oct. 11-15

American Standards Association and National Bureau of Standards, Sixth Annual Conference on Standards (includes tour of National Bureau of Standards), Sheraton Park Hotel, Washington, D. C. Oct. 24-26

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The advertising rate is $14.00 per inch for all advertising appearing on other than contract basis. Contract rates quoted on request.

New advertisements received by Aug. 2nd will appear in the Sept. issue.

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The Advertisements in this section include all employment opportunities—executive, management, technical, selling, office, skilled, manual, etc.

Positions Vacant	**Civil Service Opportunities**	**Employment Agencies**
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The Control Transmitter Section is at your service to bring business needs or "opportunities" to the attention of men in executive, management, sales and responsible technical, engineering and operating capacities with the industry served by this publication.

An employment advertisement in this EMPLOYMENT OPPORTUNITIES section will help you find the engineers you need. It's an inexpensive, time saving method of selecting competent personnel for every engineering job in the control engineering field.

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	COLOR TV, GAS, POWER & PHOTO TUBES	L	L	L
	AVIATION ELECTRONICS • RADAR	MCF	MCF	MCF
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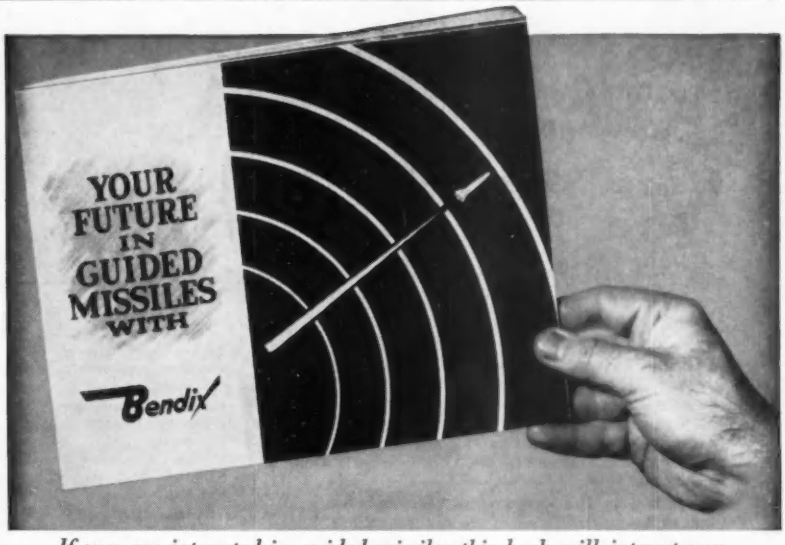

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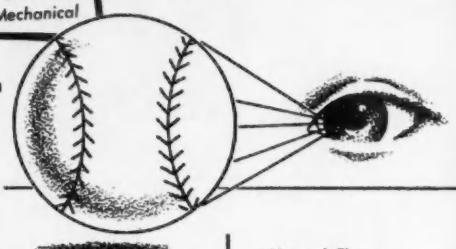

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Advertising In This Issue

A

Adams & Westlake Co., The..... 29
AGA Div. Elastic Stop Nut Corp. of America 107
Airpax Products Co..... 10
American Electric Motors, Inc..... 28
Ampex Corporation 40
Arens Controls, Inc. 102
Assembly Products, Inc. 110
Avien, Inc. 15

B

B/W Controller Corporation..... 112
Baldwin-Lima-Hamilton Corp..... 5
Barber-Colman Co. 8, 9
Bendix Aviation Corp.
Computer Division 27
Pacific Division 35
Berkeley Division
Beckman Instruments, Inc..... 83
B-I-F Industries, Inc. 102
Black, Sivalls & Bryson, Inc..... 25
Borg Corp., The George W..... 104
Builders-Providence, Inc..... 102

C

Canning, Sission & Assoc..... 110
Cinema Engineering Co..... 112
Clapp & Poliak, Inc. 30, 31

D

Daystrom Instrument 21
Doelcam Div. Minneapolis-Honeywell 20

E

Electric Auto-Lite Co., The..... 104
Electric Regulator Corp..... 95
Electronic Associates, Inc..... 99
Electrons, Incorporated 34

F

Federal Telephone & Radio Co... 19
Fischer & Porter Co.....Fourth Cover
Ford Instrument Co., Div. of Sperry Rand Corp. 93
Foxboro Company, The.....44, 45

G

Gamewell Company, The..... 111
Giannini & Co., Inc., G. M..... 7
Goodyear Aircraft Corp..... 1

H

Hammarlund Mfg. Co., Inc., The 2
Hartford Steel Ball Co., Inc..... 6
Helco Products Corp..... 107
Hills-McCanna Co. 109
Hughes Research and Development Laboratories 115

K

Kearfott Co., Inc..... 101
Kellogg Switchboard & Supply Co. 100

L

Librascope, Inc. .....Second Cover

M

Manning, Maxwell & Moore, Inc. 33, 88
Marsh Corp., Jas. P..... 108
McGraw-Hill Book Co., Inc..... 98
Miniature Precision Bearings, Inc. 84
Minneapolis-Honeywell Brown Instruments Div..... 113
Moog Valve Co., Inc..... 39

N

Norden-Ketay Corporation 22, 23
North Electric Mfg. Co., The..... 24

O

Ohmite Manufacturing Co..... 17

P

Polytechnic Research & Development Co., Inc. 96

R

Radiation, Inc. 86
Radio Corp. of America Electron Tubes Div..... 103
Recora Co., The..... 96
Reeves Instrument Corp. 46
Remington Rand Div. of Sperry Rand Corporation..... 42
Engineering Research Assoc. Div. 108

S

Sigma Instruments, Inc. 32
Sorensen & Co., Inc. 36
Statham Laboratories 18
Sterling Electric Motors..... 4

T

Taller & Cooper, Inc..... 97
Technology Instrument Corp. .....Third Cover

W

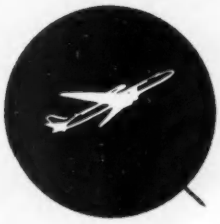
Wollensak Optical Co..... 26

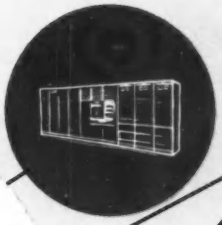
•

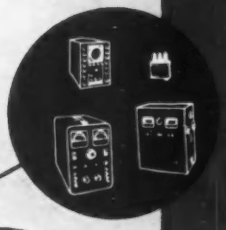
PROFESSIONAL SERVICES 122

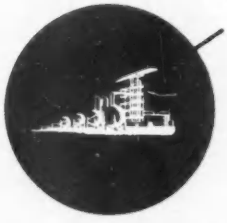
•

CLASSIFIED ADVERTISING SECTION
F. J. Eberle, Ass't. Mgr.
EMPLOYMENT OPPORTUNITIES 117-121
CONTROL TRANSMITTER
Equipment
(Used or Surplus New)
For Sale 117









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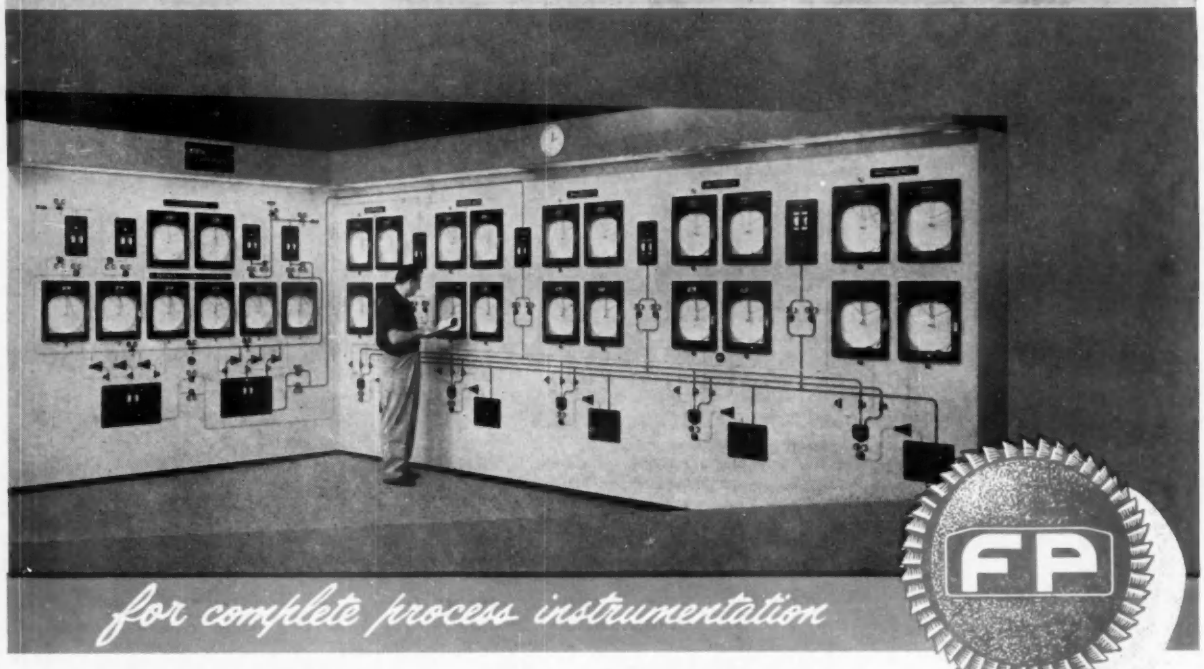

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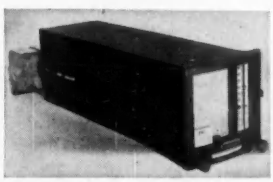

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